THE

AËRONAUTICAL JOURNAL.

(FOUNDED 1897 in succession to the ANNUAL REPORTS).

THE ORGAN OF THE ROYAL AËRONAUTICAL SOCIETY.

Published Monthly at the Offices of the Society, at 7, Albemarle Street, Piccadilly, London, W.1.
Telephone: "Gerrard 7373." Telegraphic Address: "Didaskalos, Piccy, London."
Subscriptions per annum, £2 5s.; single numbers, 3s. 9d., post free.

Edited for the Council by J. LAURENCE PRITCHARD, Associate Fellow.

All communications should be addressed to the Editor.

No. 118. OCTOBER, 1920. VOL. XXIV.

Notices of the Royal Aëronautical Society.

Lectures.

The following lectures have been arranged for the coming session. In each case an abstract only will be read at the meeting, allowing ample time for discussion. Meetings will commence at 5.30 in the afternoon in the theatre of the Royal Society of Arts, John Street, Adelphi. Members are reminded that tickets for lectures are no longer issued except for guests, and that therefore the announcements in the Journal and weekly and monthly Press form the only notice they will receive:—

1920.	LECTURER.	SUBJECT.
Oct. 7th ...	Sir F. H. Sykes, Hon. Fellow...	"Civil Aviation." Chairman: The Right Hon. A. H. Illingworth, Postmaster-General.
,, 21st ...	Sq.-Ldr. R. M. Hill, Associate Fellow	"A Comparison of the Flying Qualities of Single and Twin-engined Aeroplanes."
	Cecil Baker	"Night Flying."
Nov. 4th ...	Wing-Comdr. Flack	"The Human Machine in Relation to Flying."
,, 18th ...	H. B. Irving, Associate Fellow	"The Design of Aeroplane Control Surfaces, with Special Reference to Balancing."
	A. Fage, Fellow	"Air Screws."
Dec. 2nd ...	...	"Airship Mooring."
	Major Scott, A.F.C.	"Airship Piloting."
,, 16th ...	H. Ricardo	"Possible Developments in Aircraft Engines."
	A. J. Rowledge, Member ...	"The Instalment of Aeroplane Engines."
1921.		
Jan. 20th ...	Lord Montagu of Beaulieu, Founder Member	"The Cost of Air Ton-Miles Compared with Other Forms of Transport."
Feb. 3rd ...	G. Dobson	"Meteorology and Aviation."
	Wing-Comdr. H. W. S. Outram, Associate Fellow	"Ground Engineering."
,, 17th ...	F. Handley Page, Fellow ...	"The Handley Page Wing."
Mar. 3rd ...	J. W. W. Dyer	"Airship Fabrics."
	Major T. Orde Lees	"Parachutes."
,, 17th ...	Capt. D. Nicolson, Associate Fellow	"Flying Boat Construction."

The following course of lectures to the students of the University of Sheffield has been arranged in response to a request from the Vice-Chancellor:—

1920.	LECTURER.	SUBJECT.
Oct. 21st ...	Brig.-Gen. R. K. Bagnall-Wild	"Notes on the Inspection of Aircraft Steels."
,, 28th ...	L. Aitchison	"Aircraft Drop-forgings."
Nov. 4th ...	W. A. Thain	"Case-hardened Steels and Some Defects met with During Inspection."
,, 11th ...	L. Aitchison	"Cold-worked Aircraft Structural Steels."
,, 18th ...	A. J. Rowledge	"Materials for Aircraft from the Point of View of the Designer."
,, 25th ...	A. A. Remington	"The Economical Use of Steel in Aircraft."

Two popular lectures are also being arranged on November 4th and February 24th, 1921, in the Central Library, Fulham, at the request of the Chief Librarian.

Library.

The following books have recently been received and placed in the library:—"Aerial Navigation," J. E. Dumbleton; "The Advancement of Science, 1920"; "The Aeroplane Handbook," A. J. Swinton; "In the Clouds above Baghdad," Lieut.-Col. J. E. Tennant; "Airscrews in Theory and Experiment," A. Fage; "Australian Meteorology," Griffith Taylor; "A Text-book of Aeronautical Engineering," Alexander Klemin; "L'aeronautique Pendant la Guerre Mondiale"; "In the Blue," Major S. H. Long; "Model Aeroplaning," V. E. Johnson; "Meteorology," R. G. K. Lempfert.

Air Conference.

In response to a request from the Air Ministry arrangements are being made for the reading of a paper on "The Technical Aspects of Service and Civil Aviation," by Captain F. S. Barnwell, Fellow, at the Air Conference, to be held at the Guildhall on October 13th, at 5 p.m.

Early Members.

Members will no doubt be interested to learn that in the course of examining various old papers in the records of the Society, the Secretary has come across a number of original applications from, amongst others, the following aeronautical pioneers and prominent scientists:—Dr. Alexander Barton, Octave Chanute, S. F. Cody, Henry Coxwell, Sir William Crookes, A. E. Gaudron, Lawrence Hargrave, Hon. C. S. Rolls, Lord Rayleigh, Capt. Robert Falcon Scott, R.N., Percy Pilcher, José Weiss.

Finance.

The half-yearly audit has just been completed and the accounts show, as was anticipated, a deficit approximately equal to the amount of subscriptions outstanding. It is hoped to publish the balance sheet in the November issue of the Journal.

Founder Members.

The Secretary's attention has been called to an error in the list of new rates of subscription printed in the April issue of the Journal, whereby it appears as if persons might still be elected Founder Members of the Society. In point of fact the privilege of Founder Membership is confined to such members elected prior to November 1st, 1911. A complete list of Founder Members will be found in the new List of Members, which is now in the printer's hands.

Scottish Branch.

The Autumn Lecture Session of the Scottish Branch will open in the second week of October with a lecture by Major-General Sir William Brancker, Member, on "The Most Recent Developments in Civil Flying," to be followed in the beginning of November by a paper by Air Commodore H. R. M. Brooke-Popham, Chairman. During November the second series of technical lectures to the engineering students of Glasgow University has been arranged. Major J. S. Buchanan, Associate Fellow, will lecture on "Aircraft," and Squadron Leader R. M. Hill, Associate Fellow, on "The Technique of Flight."

Annual Dinner.

It is unfortunately not yet possible to give details of the Annual Dinner, which it is hoped to hold at the Connaught Rooms on some date between October 25th and 29th, but members will be circularised as soon as possible on the subject. Each member will be able to bring one or more guests, and it is anticipated that the charge, exclusive of wines, will be about one guinea per head.

W. LOCKWOOD MARSH, *Secretary.*

THE ROYAL AERONAUTICAL SOCIETY (SCOTTISH BRANCH).

FIRST ANNUAL REPORT FOR YEAR ENDING 31st MAY, 1920.

The Executive Committee is pleased to state that the Scottish Branch of the Society has been successful from the beginning. This is largely due to the assistance given to the Scottish movement by several members of the Executive and notably by the Right Hon. Lord Weir of Eastwood and Sir William Beardmore, Bt., President and Chairman respectively.

The splendid feat of the Clyde-built airship, R34, in crossing and re-crossing the Atlantic for the first time by air, afforded a unique opportunity to the Scottish Branch to make its existence known, and of this it took full advantage. To commemorate the remarkable event, the Chairman, Sir William Beardmore, whose company built R34, decided to entertain the officers and crew to a public luncheon. This important function was arranged by the Society and a wide amount of interest was evoked in the city and in the west of Scotland generally. At the welcome meeting in St. Andrew's Hall in the evening, a gathering was present of over 3,000. The general effect was that about 200 members joined the Society, a number which, apart from the favourable circumstances connected with the never-to-be-forgotten feat of the Dalmuir airship, might not have been attained for years.

Lectures for the members and open to the public have been delivered in the Hall of the Institution of Engineers and Shipbuilders as follows:—

Wednesday, 14th January.—Capt. Alston, R.A.F., on "More War Experiences."

Tuesday, 20th January.—Mr. J. S. Nicholson, O.B.E., D.Sc., Glasgow University, on "The Development of Metal Construction in Aircraft."

Wednesday, 11th February.—Col. Outram, London, on "Safety in Flight."

Wednesday, 25th February.—Professor Cormack on "Water Cooled and Air Cooled Engines."

Wednesday, 10th March.—Capt. Latta on "Civil Aviation from the Private Owner's Point of View."

Wednesday, 24th March.—Capt. Worthington, Assistant Director of Research, Kite Balloon Section, Air Ministry, on "Kite Balloons in Peace and War."

Monday, 26th April.—Mr. J. L. Cope, F.R.G.S., on "Aeronautics in Connection with the Proposed South Antarctic Expedition."

Wednesday, 6th May.—Squadron-Leader Wimperis, O.B.E., on "How an Airman Finds His Way."

The average attendance was about 175. The widespread interest among the engineering students of Glasgow University has been particularly marked. Those at the University and Technical College who sent in their names as interested in aeronautics and desirous of obtaining the literature of the Society number over 800. A large number of those are ex-Air officers and the Scottish Branch has undoubtedly performed a great public service in getting in touch with these and in bringing them together. A number of the ex-Air officers are

preparing for the serious study of aeronautics and a considerable correspondence with these of a useful kind has evolved both in attendance and also during the vacation. Satisfaction in meeting such a splendid body of young men has been expressed by all the lecturers, and no less satisfaction has been expressed by the students themselves in regard to the facilities provided them. It is intended to keep in touch with them by means of the card system so that as many as possible may become members of the Society within two or three years' time, when they have taken up their profession actively in various parts of the world.

A special scientific course of lectures on aeronautics in the University, suggested by Professor Cormack and Mr. James G. Weir, C.M.G., has also met with success. Three lectures were delivered by Lt.-Col. Bristow, of London, on "Engines," and by Squadron-Leader Wimperis, O.B.E., of London, on "Navigation and Meteorology." It is proposed that this course be continued in the autumn by Colonel The Master of Sempill and by one of General Brooke-Popham's assistants in the Directorate of Research. The attendance at the Glasgow course averaged 84 at the first series and 66 at the second. In Edinburgh University, where the lectures were repeated, the attendance averaged 110 for the first series and 100 for the second; in Dundee University College the numbers were 45 and 40. So great was the interest manifested by the students that the University authorities of Glasgow have now decided to institute a half graduation course in aeronautics next session (1920-21). Advantage was taken of the presence in Glasgow of Squadron-Leader Wimperis to lecture to the Cadets of the Glasgow and Edinburgh Public Schools. The attendance at Glasgow was about 275, when Lord Weir presided, and in Edinburgh about 450, when Lord Scott Dickson presided.

As the success of these activities involved considerable expense it was decided to put the finances of the branch on a satisfactory footing by instituting a special Initial Establishment Fund. By this means, and notably through the generosity of Lord Weir, Sir William Beardmore and Mr. W. H. Coates, a fund of about £1,000 has been raised, which should be sufficient to carry the Society through the initial stages and early years until the income from subscriptions has been sufficiently built up to enable the branch to carry its own weight.

In Edinburgh the work of the Society is making good progress and a strong Executive has been formed with Sheriff Crole, K.C., Sheriff of the Lothians, as chairman. Professor Hudson Beare has been so energetic and helpful that the attendance of the scientific course was even higher than in Glasgow, and hearty thanks are due to him for all he has done to promote the science of aeronautics in Edinburgh.

In Dundee there has also been considerable heartiness shown. The branch has benefited by the hearty support of the Lord Provost, of Principal Mackay and Professor Gibson, who is one of the leading scientific exponents of Aeronautical Science in Scotland. Mr. Angus R. Furton, D.Sc., Assistant Professor of Engineering, is acting as Secretary.

The Executive should not omit in this report to express their feelings of gratitude towards the Universities of Glasgow, Edinburgh and Dundee for all the lecture facilities afforded so generously and for the contributions towards the cost of the scientific course.

In regard to matters connected with aeronautics generally the Scottish Branch has not been idle. There has been constant correspondence with the Air Ministry in regard to many points of importance relating to Scotland and the unvarying courtesy and sympathy of the Air Ministry are cordially acknowledged. Among other matters the Executive has considered the question of promoting a Scottish School of Aeronautics for the practice and training of the many Air officers in

Scotland. It has been felt that if a Territorial Air Force is to be established opportunities for its development should be afforded in the neighbourhood of Glasgow and Edinburgh in connection with the aerodromes at Renfrew and Turnhouse.

It has been difficult to prevent these fine aerodromes from falling into the hands of strangers and the ground given up to house building, but this danger has been averted for the moment. It is hoped that through the efforts of the Society and the Corporations of Edinburgh and Glasgow, together with the Universities in these cities, both aerodromes may be conserved for the purposes for which they were built. "The Committee on Education and Research in Aeronautics," appointed by Lord Weir in October, 1918, especially in regard to the Zaharoff Professorship, in their report recently published, points to aeronautical training of Cadets being limited to England. But the Executive consider there is ample material for a Scientific School of Aeronautics in Scotland, and they propose during the coming year to get all the Scottish authorities interested so co-ordinated that Scotland may become the great aeronautical training ground which the engineering students of Glasgow, Edinburgh and Dundee are capable of making it.

The work of the past year is thus only the earnest of more useful work in the time to come. The branch was not started a moment too soon, for already the Air League of the British Empire is inviting co-operation in Scotland and the Royal Aero Club is similarly in hearty sympathy.

Indebtedness is due to many friends throughout Scotland who have contributed to make the first year of the Society in Scotland so successful as to have drawn praise both from the Head Office of the Society and also from the Air Ministry.

W. Beardmore, *Chairman.*

J. Buyers Black, *Hon. Sec.*

THE ROYAL AERONAUTICAL

ABSTRACT OF ACCOUNTS FOR

RECEIPTS.

				£	s.	d.
ORDINARY—						
Entrance Fees and Annual Subscriptions Received				225	15	0
EXTRAORDINARY—						
Amount received for Tickets for the R.34 Reception	£50	17	1			
Special Donation	5	5	0			
Special Subscriptions for Initial Establishment Fund	910	0	0			
Grant from Glasgow University towards cost of Scientific Course of Lectures on Aeronautics in Glasgow University	25	0	0			
Grant from Edinburgh University	25	0	0			
Grant from Head Office, London, towards cost of founding the Branch	60	0	0			
Interest on Deposit Receipts	3	1	3			
				1079	3	4
				£1304	18	4

GLASGOW, *3rd August*, 1920.—Audited and found correct.

SOCIETY (SCOTTISH BRANCH).

THE YEAR ENDED 31st MAY, 1920.

EXPENDITURE.

	£ s. d.	£ s. d.
ORDINARY—		
Amount paid Head Office, London, being one-half of Annual Subscriptions received by this Branch to 31/3/20 as per arrangement	91 17 6	
Miscellaneous Expenses of Lectures	17 15 6	
Printing	59 12 0	
Typewriting Supplies, Stationery, etc.	19 16 6	
Postages, Telegrams and Trunk Calls	38 10 3	
Clerical Assistance from 1/9/19 to 31/5/20 ...	78 18 4	
		306 10 1
EXTRAORDINARY—		
R.34 Meeting Expenses—		
St. Andrew's Hall Charges ... £20 12 6		
Sundry Charges 6 0 0		
Entertainment Tax 9 17 9		
Printing and Bill Posting 24 14 6		
Travelling Expenses of Crew ... 4 19 0		
Organist 3 13 6		
Advertising 46 18 0		
Film Operator 1 11 6		
	118 6 9	
Hon. Secretary's Travelling Expenses forming Branches and addressing Air Officers at Scottish Air Stations	20 0 6	
Sundry non-recurring Charges	22 7 6	
Paid for Use of Office and Staff, Typewriters, and Sundry Expenses, from 1/5/19 to 31st August, 1919	60 0 0	
Bank Interest	1 17 2	
		222 11 11
Balance; surplus of Receipts over Expenditure made up as follows—		
Cash in Bank on Current Account	52 13 11	
Cash in Bank on Deposit Receipt	713 1 3	
Cash on hand	10 1 2	
		775 16 4
		£1304 18 4

(Sgd.) WYLLIE GUILD & BALLANTINE, C.A., *Auditors.*

ABSTRACT OF LECTURE BY SQUADRON-LEADER R. M. HILL on

A COMPARISON OF THE FLYING QUALITIES OF SINGLE AND TWIN-ENGINED AEROPLANES.

(1) **Introduction.**—The best way to analyse the flying qualities of twin-engined aeroplanes is to examine the accumulated fund of experience on single-engined aeroplanes, to deduce first principles from it, and apply them to twin-engined aeroplanes.

(2) **Control and Design.**—Control may be divided in two: Control of the aeroplane and control of the engines. The key to the problem is the correct appreciation of their interreaction.

(3) **Effect of Engine on Control.**—Intentional variation of engine power or engine failure affect the aeroplane in four main directions.

(4) **Effect on Single-Engined Aeroplanes.**—The above four effects are applied in detail to the single-engined type, and some practical examples are given.

(5) **Effect on Multi-Engined Aeroplanes.**—Only two of the above effects vitally concern the multi-engined type, and these are discussed in detail.

(6) **Details of Engine Controls on Multi-Engined Aeroplanes.**—The means at the pilot's disposal for controlling the engines are discussed.

(7) **Practical Flying Notes on Twin-Engined Aeroplanes.**—These notes are based on the writer's experience of twin-engined aeroplanes, and are mainly concerned with the pilot's ability to deal with the sudden failure of one engine in flight near the ground.

(8) **Conclusion.**—A justification is given for the attitude of extreme caution adopted in the remarks on the flying of twin-engined aeroplanes, and the importance of the careful study of type peculiarities is emphasised.

The above is an abstract of the paper which will be delivered at the Royal Society of Arts, on October 21st, at 5.30 p.m.

CORRESPONDENCE.

To the Editor of the AERONAUTICAL JOURNAL.

DEAR SIR,—I notice in the August number of the AERONAUTICAL JOURNAL, in the report of the discussion on Major Linton Hope's paper on "Flying Boat Hulls," page 466, that the remarks contributed by me to that discussion have been included in the contribution of Lieutenant-Colonel Travers.

As my knowledge of Colonel Travers' opinions leads me to suppose that he will not altogether agree with my remarks, I think it would be well if this error were pointed out in the next issue.

Actually my part of the discussion starts at line 8, "His practical experience," etc., and continues to the beginning of Mr. Gibson Knight's contribution.

I am, yours faithfully,

W. H. SAYERS.

WIRE CABLES.

BY WALTER A. SCOBLE.

Introduction.

High tensile steel wire has many uses in connection with aircraft. A single wire has the advantage of a high breaking stress, greater than that of the bulk material from which it is made, because, as Goodman* has pointed out, the drawing produces an elongated stricture of the steel, and the wire strength approximates to the true breaking stress of a larger specimen, which is the tension the latter resists at the moment of fracture divided by the reduced area. The British Engineering Standards Association's specification, 2W1., requires a minimum breaking stress of 80 tons per sq. in. up to 0.160in. diameter, 90 to 0.116, and 100 to 0.064. These stresses can safely be exceeded when required particularly with wire of small diameter.

The minimum breaking load of the largest wire specified, 0.160in. diameter, is 3,603lbs. If greater strength be required it is in general advisable to employ several wires laid up together, because larger wire would be too awkward to handle. Other considerations which operate in the same direction are the low efficiency of simple end connections for large wire under service conditions, and the higher tensile strength of smaller wire.

When strength to withstand tension is the primary consideration, the material used is called a straining cord. Except in the largest sizes it consists of a single strand of wires. The simplest strand is formed by laying six wires round a central wire. The next stage in the development is to add another layer of 12 wires over the six to make a 19-wire strand. Another eighteen wires of the same diameter may be twisted on to give a 37-wire cord. Nineteen wires are used thus for straining cords with breaking strengths from 10 to 25 cwts. and 37-wires onwards to 135cwts. The specification also includes 150, 165, and 180cwt. cords, but for these a cable of low flexibility is used, consisting of six strands of seven wires laid on a seven-wire core. The cable is made up of seven strands in the same way that each of its strands is composed of seven wires.

The larger straining cords do not lend themselves to the making of an efficient end connection, and they are not so easy to handle as cables of equal strength which are built up of more wires of smaller diameter. The latter reason probably accounts for the general preference for extra flexible cables over straining cords, but the former consideration has justified and enforced the choice in some instances. Where the cable is required to be flexible, as in use over pulleys, the extra flexible ropes must be used.

The 5cwt. extra flexible cable consists of four strands, each of seven wires, and the 10 and 15 cwt. sizes of four strands of 19 wires, all laid on fibre cores. The four-strand construction was, I believe, suggested by Mr. C. Selby, of Bullivants, during the war, to increase output, and up to the present it is retained. The normal construction is seven strands of 19 wires, but it is replaced by 7 x 37 for 120, 140, 160cwt. cables.

Still another class of ropes is formed by those used in connection with kite-balloons, and these are covered by a separate specification. They may briefly be described as having to provide a maximum strength for weight with a medium flexibility. These ropes have to work over pulleys, but not continuously, but the considerations of ease in handling and coiling on a drum support the demand for a moderate degree of flexibility.

---

* "Mechanics Applied to Engineering"

A considerable number of tests have been made on cables of each class, first to decide on the best form for the kite-balloon cable, then to gather further information and to deal with matters which demanded attention during manufacture, and also in connection with many other points which arose with reference to airship rigging, bending over pulleys, and the other numerous applications of this useful material.

The data gathered is now dealt with under various subject headings. In some cases the full experimental results would occupy far too much space, or their consideration would require the inclusion of too many figures, therefore only the general conclusions are given.

The Efficiencies of Wire Cables (Preliminary).

The efficiency of a cable is here taken as the ratio of the strength of the completed cable to the sum of the strengths of the component wires. This efficiency is obviously very important for ropes which are loaded in tension only. It should be noted that the strength of the rope has comparatively little bearing on the tension which can be allowed when the rope is repeatedly bent over a small pulley. If a number of wires were laid parallel the strength of the whole would be less than the aggregate strength of the wires, because the load would not be shared equally amongst them, some would take too high a proportion and would break first. In a cable there is further unavoidable loss because the stranded wires and the strands themselves are inclined to the axis of the rope.

The first estimate of efficiency was made before apparatus had been set up to make accurate tests of the individual wires, but since it gave valuable information, which was confirmed by more complete tests, the data is given here in Table 1.

TABLE 1.

EFFICIENCY OF CABLES TO TAKE TENSION.

Cable.	Tensile Strength. Tons.	Weight. lbs./ft.	Tensile Strength. / Weight per foot.
.255in. C. on telephone core	2.9	0.109	26.6
.255in. C. on hemp core	3.0	0.104	28.8
7mm. C. on telephone core H.	4.0	0.129	31.0
7mm. B. 7 x 19	4.1	0.130	31.5
7mm. C. on telephone core F.	3.8	0.126	30.2
9mm. N. Lang's Lay. Hemp core ...	5.1	0.190	26.8
8.4mm. C. Soft wire core	5.3	0.204	26.0
8.4mm. B. 7 x 19	7.1	0.206	34.5

The best result was given by the 8.4mm. B., with the 7mm. B. cable next, each of which had a wire core similar to the strand. The Lang's Lay and ropes with soft cores, whether of wire or hemp, were heavy for their strengths.

A seven-strand is as efficient as a six-strand rope, but the use of a centre strand of lower tensile wire adds weight, in comparison with a hemp core, and probably leads to little increase of strength.

It is also interesting to note that whereas the Lang's Lay is employed to give long life by providing a greater bearing area for wear over pulleys, the efficiency shown is equal to that of the ordinary lay adopted by a manufacturer of high repute.

In order that the comparisons shall be understood, and certain products of the makers not misjudged, it is desirable to emphasise the fact that cables are divided into two broad classes, those which are required to have a high tensile

strength to take tension, and those which have to work over pulleys. The conditions are entirely different in the two cases. Certain makers excel with ropes of one class, and there are indications that they do not pay sufficient attention to the distinction drawn above, but embody the features in both kinds which they consider to be suitable for that class in which they specialise.

Tests of Wire Rope under Tension, Shock and Vibration.

Cables are frequently subjected to tension, shock and vibration in service, so test lengths were treated in a similar fashion in the laboratory. A bed was set up on which a ten foot length of cable could be put in tension, be vibrated at its centre by means of a powerful electro-magnet, and be subjected to end shocks by a repeated shock machine of the pendulum type.

Three types of tests were made, (1) plain tension of a specimen about ten feet long, as a standard for comparison; (2) the rope was subjected to combined tension, vibration and shock for a definite time and was then broken in plain tension; (3) the rope was put under tension, vibration and shock and the tension was stepped up at intervals until the cable fractured.

It was found that the stress produced in the rope by the shock must be added to the main tension. With the same blow the shock stress is greater in a larger cable loaded to the same fraction of its breaking strength, but it is less with Lang's Lay than with ordinary lay because the former gives a lower elastic modulus for the rope.

In every case the strength of a cable in plain tension was increased by previous vibration and shock treatment. Some results for the 8.4mm. B. rope are given to illustrate these points.

1. New piece broken in plain tension at 7.1 tons.
2. Put under vibration and shock at a tension of 4.1 tons for five hours, then broken in plain tension at 7.3 tons.
3. One hour at 4 tons tension with vibration and shock, one hour at 4.5 tons tension with vibration and shock, three hours at 5 tons tension with vibration and shock, three hours at 5.5 tons tension with vibration and shock, three hours at 6 tons tension with vibration and shock, two and a half hours at 6.5 tons tension with vibration and shock, broken under treatment.
4. Vibration and shock under a tension of six tons for 49 hours. Then broken in plain tension at 7.7 tons.

In order to give the highest tension efficiency each wire in a cable must carry its share of the load up to the point of fracture. It appears certain that the effect of the shock and vibration is to make the wires give and take somewhat, to bed together better, and thus to spread the tension more evenly. In this fashion the efficiency of the cable is increased and its tensile strength is raised.

Conditions which affect the Efficiency of a Cable in Tension.

Table 1 shows that a seven is as efficient as a six-strand cable. At first it appears that a soft wire core adds weight with but little increase of strength, but then it is noticed that some samples with hemp or telephone cores have not much greater efficiency.

Individual wires of a number of 8.4mm. specimens were tested, and in some cases single strands were broken, with the results shown below.

TABLE 2.

EFFICIENCIES of 8.4mm. CABLES.

Cable.	Previous Treatment.	Aggregate strength of wires.	Strength of strand.	Strength of cable (new).	Efficiencies. Strand.	Cable (new).
8.4mm. B. 7 × 19 × .023"	70 minutes 5.5 tons + V. + S.	8.36 tons.		7.1 tons.		0.85
,,	49 hours 6 tons + V. + S.	8.24 ,,		7.1 ,,		0.862
,,	New.	8.27 ,,	1.12 tons.	7.1 ,,	0.95	0.859
8.4mm. C. 6 × 19 × .022" over 16 × .026" + 1 × .0175".	T. + V. + S. to fracture.	6.39 ,, 0.98 (core).		5.3 ,,		0.72
,,	82 minutes 4.1 tons + V. + S.	6.6 + 0.95		5.3 ,,		0.702
,,	New.	6.81 + 0.96		5.3 ,,		0.682
8.5mm. C. on telephone core.	Broken in plain tension.	6.46.		4.4 ,,		0.681
,,	New.	6.11.	0.952 ,,	4.4 ,,	0.934	0.73

Soft core wires were cut into short pieces during a tension test of the cable. The wires were more uniform in the " B " cables which had the higher efficiencies, and the wire strengths varied more in a "C " sample, which broke at a lower load than a more representative specimen. This is an indication of the desirability of uniform wire, and was supported by the " B " being more efficient than the " C " strand. The poor " C " samples were the first which had a number of odd wires broken, apart from the main fracture, after a tension test. This feature of cable fractures will receive further consideration later, but in this instance the odd wires were broken early because their tensile strengths were abnormally low.

High tensile wire for cables must not be brittle, but the degree of ductility possible is evidently limited. When a rope is tested under tension to fracture the weak wires yield first, but if they are too weak, or have insufficient ductility to allow them to stretch without breaking until the whole of the wires are fully stressed, they fracture prematurely and therefore do not contribute fully to the ultimate strength of the cable. It has been noticed in some tests that so many wires have broken early that the sum of the strengths of the remainder could not have greatly exceeded the ultimate strength of the rope. This is probably accounted for by the fact that premature fractures due to weak wire are spread along the rope, and therefore some of the broken wires, by being locked in the strand, are still able to carry a certain load at the point of fracture.

The Bearing of the Length of Lay on the Efficiencies of Strands and Cables.

Further comparative tests of separate wires and of the whole strands from which they were taken showed that the strand efficiency varied from .918 to .97, the " C " being usually lower than those of " B " construction. The .918 is certainly a low result, but not sufficiently so to account for the weakness of the " C " ropes. Measurements of the cables available were collected in a table to enable an estimate to be made of the effect of pitch or lay on efficiency.

TABLE 3.

Cable.	Strand Diam. Inch.	Pitch of outer wires of Strand.	Diam. Cable Inch.	Pitch of Strand.	Measured Effcy. of Cable.	Calculated Effcy. of Cable.*	Pitch of Strand. Outside diam. of Cable.
"B," 8.38mm. No. 3 ...	.117	1.47	.353	2.74	.86	.85	7.75
"B," 6.9mm.			.273	2.32		.81	8.5
"C," 8.38mm.	.1128	1.36	.355	2.00	.72		
					.70	.68	5.6
"C," 8.5mm., on telephone core F. ...			.352	2.06	.68	.68	5.85
"C," 10mm., on telephone core F. ...			.369	2.61		.68	7.1
"C," 7mm., on telephone core H. ...			.305	1.90		.71	6.2

The longer lay "B" cables were more efficient than the "C," but the 10mm. "C" rope was no better than the average of this set, although it had a much longer lay. Consequently it was not altogether clear how much of the difference was due to the length of the lay and how much to better rope making. Samples were prepared by each maker to settle this point.

For the "B" specimens a strand was laid up composed of 19 wires of .023in. diameter. This strand was used for the core and outer strands of two cables, one of which had the "C" lay of two inches and the other that adopted by "B," namely $2\frac{3}{4}$in. The former broke in tension at 5.2 tons and the latter at 6.55 tons, each tested on a 10ft. length. Assuming an average breaking stress for the wire of 140 tons per sq. in., the efficiencies were approximately 67 and 85 per cent. respectively. The comparison was not quite fair to the "C" lay sample because the short pitch should have been associated with a core of larger diameter than that of the outer strands.

When six strands are laid on a similar core the circumference of the circle through their centres is $2\pi d$, where "d" is the diameter of the strand. The sum of the diameters is 6d. The greatest angle at which the strands can be laid and bear properly on the core is $\cos^{-1} 6/2\pi$, that is $\cos^{-1} .954$ or $17\frac{1}{2}$ degrees nearly. The tangent of this angle is .314, which leads to the conclusion that the lay should not be less than 20 times the diameter of the strand, or 6.67 times the diameter of the rope. The ratio for the above short lay sample was only 5.7, whereas the "B" lay makes it 7.8.

Six specimens were prepared and reported to be all made from the same strand of 7 x 19 x .022 inch construction. This was correct for three of them, but the others were of the usual "C" make with cores of lower tensile wire. The test results are collected :—

Number.	Type of core.	Lay inches.	Breaking load.
1	as strand	2.32	5.42 tons
2	,,	2.87	5.92 ,,
3	,,	3.27	6.17 ,,
4	lower tensile wire	2.11	5.59 ,,
5	,, ,,	2.64	5.69 ,,
6	,, ,,	2.95	5.62 ,,

The greatest jump in strength was between Nos. 1 and 2, where the lay changed from 6.6 to 8.1 times the rope diameter, or from slightly below to well over the minimum calculated value. The further increase of pitch did not yield so large an increase of strength. The strengths were all below that of the "B"

* Wires taken as of the rated diameter and of breaking strength 150 tons per sq. in.

sample made to the " B " lay, which approximated most closely to No. 2. It was remarkable that an increase of lay did not increase the strength of a rope with a low tensile wire core. It almost appeared that the core was cut through by the outer strands at a certain tension, and that when it failed the remainder of the cable could not carry any more load.

It was clear that a lengthening of the lay strengthened the cable, particularly when the increase changed the rope from a hollow to a solid one. But it was also evident that the efficiency depended very considerably on the details of manufacture which are generally included under the title of ropemaking.

Torsion Tests of Wires from Cables.

If a wire cable be taken to pieces, particularly after certain kinds of treatment, it is found that the separate wires are nicked in places. Unless the nicking be severe it has no very appreciable effect on the tensile strength of the wire, but the number of torsion turns which cause fracture is reduced by the wire breaking at a nick. The torsion test is the best method for indicating the amount of damage caused by the cutting, which at an advanced stage reduces the tensile strength of the wire.

A few representative results have been taken from the large number available and are included to support the conclusions which have been reached from tests of this type. The sets are lettered to simplify the references.

" A " refers to the wires of a strand of a new piece of cable. Any damage which is revealed by the torsion must be the result of the laying up of the rope. In this example it is found that the inner wires are normal, whereas four of the twelve outer wires give somewhat low results. These wires have been nicked, but not sufficiently to reduce their tensile strengths. " C " refers to another new cable in which only one outer wire of the strand torsioned badly. Tests of several hundred samples of new rope have shown that a wire which has its tensile strength reduced by the laying up is rarely found, but on the average one or two of the outer wires of each strand give a reduced number of twists before fracture.

Set " B " is important because it shows that a wire gives a normal torsion test after it has been broken by simple tension.

The diameters of the wires were measured in all cases, but they are omitted from many of the tables where they have no bearing on the results.

TESTS OF SINGLE WIRES.

New piece of B Cable, 6 × 19 × .025in. over Telephone Core. . (A.)

Tension Tests of Wires from One Strand.

	Centre.	Six.						Outer.		
Diameter, in. ...	.0250	.0252	.0257	.0250	.0252	.0252	.0254	.0252	.0253	.0251
Load, lbs. ...	157	162½	166	159¾	156	163	155½	160	173	158½
Stress, tons/sq. in.	143.1	145.5	143.0	145.5	139.6	146.0	137.2	143.1	154.1	143.4

Diameter, in. ...	.0251	.0251	.0256	.0253	.0252	.0252	.0250	.0250	.0254
Load, lbs. ...	158	163	157½	157	158½	155½	157½	159½	155
Stress, tons/sq. in.	143.0	147.6	136.5	140.0	141.9	139.0	143.5	145.3	136.7

Torsion Tests of Wires from One Strand.

	Centre.	Inner Six.													
Turns in 8in.	105	129	124	113	126	127	116	102	129	114	122	65	83	87	128	68
										128	128	130				

Samples of Wire as used for B Cables. . . . (B.)

Torsion Tests made on Wires broken in simple Tension.

Diameter, in. ...	.0230	.0230	.0230	.0232	.0232
Tension, lbs. ...	141.5	141.5	138.5	143	143
Turns in 8in. ...	133	136	132	124	131

New Piece of B Cable, No. 3, $7 \times 19 \times .023$in. Torsion. . (C.)

	Centre.	Inner Six.				Outer.										
Turns in 8in.	107	126	126	127	125	110	133	128	109	128	126	111	54	124	129	126	126	127	107

B Cable, No. 3, $7 \times 19 \times .023$in., $22\frac{3}{4}$ hours at 3 tons + V + S. . (D.)

Cable not broken. Wires from Core. Torsion.

Turns in 8in. ...	141	118	140	101	106	133	122	127

Wires from Outer Strand.

Turns in 8in.	125	128	126	130	123	131	131	109	112	122	112	138	131	143	128	136	133	116	126

B Cable, $7 \times 19 \times .023$in. Broken by plain Tension. . . (E.)

Torsion of Wires from Unbroken Strand opposite Fracture.

	Centre.	Inner Six.						Outer.									
Turns in 8in.	26	111	48	96	58	132	96	59	53	20	19	51	40	32	36	53	48	35	42

B Cable, No. 3, $7 \times 19 \times .023$in., 48 hours at 6 tons + V + S. . (F.)

Wires of Broken Strand.

	Centre.	Inner Six.					Outer.								
Turns in 8in.	130	129	132	137	136	58	103	83	95	86	53	99	78	74

B Cable, No. 3, $7 \times 19 \times .023$in., 5 hours, 4.1 tons + V + S, then tension 7.3 tons. (G.)

Wires of Broken Strand.

	Centre.	Inner Six.					Outer.								
Turns in 8in.	48	50	58	147	109	73	63	91	40	27	99

C Cable, 8.4 mm., $7 \times 19 \times .022$in. . . . . (H.)

Broken in plain Tension at 5.3 tons. Wires from Broken Strand.

	Centre.	Inner Six.						Outer.									
Turns in 8in.	104	126	117	115	105	129	133	99	101	114	93	98	115	99	114	108	99	95	104

C Cable, $6 \times 19 \times .022$in. over Telephone Core. Broken in plain Tension 4.45 tons. (I.)

	Broken Strand.										
	Centre.	Inner Six.						Outer.			
Diameter, in.	.026	.0225	.0225	.0225	.023	.0225	.0225	.0215	.0212	.0215	.0212
Turns in 8in.	101	62	93	84	69	60	64	95	72	80	80
Diameter, in.	.022	.0215	.022	.0212	.022	.022	.0215	.022			
Turns in 8in.	82	102	89	83	93	98	84	102			

B Cable, 6 × 19 × .023in. over Telephone Core. Broken in plain Tension at 5.9 tons. . . . . (J.)

Broken Strand close to Fracture.

	Centre.	Inner Six.						Outer.											
Turns in 8in.	123	126	136	129	118	117	84	69	65	31	74	72	48	36	75	80	72	53	68

C Experimental Cable, No. 1, 7 × 19 × .022in. Broken in plain Tension. (K.)

Broken Outer Strand.

	Centre.	Inner Six.						Outer.											
Turns in 8in.	120	149	116	80	48	138	127	68	77	82	104	81	88	100	76	56	105	17	92

C Experimental Cable, No. 5. Untested piece. . . (L.)

	Outer Wires.						Inner Six.			Centre.
Turns in 8in.	127	143	126	138	129	132	129	126	78	25

C Experimental Cable, No. 5. Broken in plain Tension. . (M.)

Outer Broken Strand.

	Outer Wires.											Inner Six.						Core—23
Turns in 8in.	78	65	58	63	87	62	30	34	84	58	61	85	117	141	127	93	123	55

B Experimental Cable, 7 × 19 × .023in. Lay 2 inches. Broken in plain Tension. (N.)

Broken Strand at Fracture.

	Centre.	Inner Six.						Outer.											
Turns in 8in.	130	136	144	139	126	112	146	114	80	117	22	110	118	20	108	109	68	98	107

Wires from Unbroken Strand at Fracture. . . . (O.)

	Inner.		Outer Wires.									
Turns in 8in.	141	121	39	35	66	60	73	92	6	39	85	33	66

B Experimental Cable, 7 × 19 × .023in. Lay 2¾ inches. Broken in plain Tension. (P.)

Wires from Core near Fracture.

	Centre.	Inner.						Outer.											
Turns in 8in.	4	122	109	119	120	122	125	47	53	99	97	87	90	62	70	85	71	34	95

TORSION TESTS OF WIRES TAKEN FROM CABLE AFTER USE ON A KITE BALLOON.

C Cable, 6 × 19 × .0225in. round, 17 × .025in. (lower tensile wire). . (Q.)
2-9 Bolt Clips to form Eye. Tests of Flying End.
Part of Strand 8 feet from Loop.

	Outer.											Inner Six.				
Diameter, in.	.022 to .023									.023 .024	.022 .023	.022 .023	.023 .024	.022 .023		
Turns in 8in.	68	124	112	98	72	112	117	94	110	56 64	110	145	73 120 105	132 81 120	122	

At Point where Lower Clip was Attached. . . . (R.)
Outer Wires.

Diam., in.	.0218	.0222	.0222	.0225	.0226	.0230	.0233	.0228	.0225	.0240	.0230
Turns in 8in.	85	88	117	124	96	66	42	94	43	29	66

	Inner Six.						Centre.
Diameter, in.	.0230	.0222	.0222	.0235	.0220	.0225	.0240
Turns in 8in.	133	147	122	110	114	127	102

Under Top Clip. . . . . (S.)
Outer Wires only.

Diameter, in.	.0222	.0220	.0230	.0210	.0205	.0210	.0227	.0230	.0215	.0218	.0225	.0218
Turns in 8in.	110	134	116	119	77	82	123	107	133	126	122	130

Half load tension combined with vibration and shock over a considerable period "D," caused practically no damage, but after fracture by plain tension the outer wires were severely cut, "E," and the nicking of some of the inner wires was almost as serious. "G" also indicates damage throughout the strand after the cable has been broken, but in "F" and "H" only the outer wires show much depreciation.

The next two cables were closed over telephone cores, so that the nicking must have been caused by the outer strands bearing on each other. The "C" rope had a large centre wire in the strand, and the inner six were a point larger in diameter than the outer wires. In this case, "I," all the wires were damaged after the cable was broken. "B" cable had the same wire throughout and of the inner six only one showed a slight reduction of the number of turns, "J."

This method of comparison showed no advantage gained by the "C" cable which had a core of larger, low tensile wire, "M," over that which had seven similar strands, "K." Indeed the former gave rather poorer results, particularly so if the lower breaking load of the cable be allowed for.

It is clear that the most severe cutting is local, the wires of an unbroken strand opposite fracture being badly nicked, "O" and "E," whereas the wires from a strand which actually fractured under similar or even more severe treatment, "N" and "F," are necessarily tested a short distance away from the break and give higher average torsion results.

The long lay " B " sample, " P," was quite satisfactory when judged by this standard. In this case it was noticed that several wires were hard and brittle over a length of about 1½in. from the point of fracture, but were normal farther away. Apparently there had been local stretching of the wire which caused the hardening.

The nicking is most severe after a cable has been broken by plain tension, and the addition of vibration and shock does not cause a further depreciation of the wires in the region of the fracture.

The damage to the outer wires of the strands of a long lay cable is slightly more severe than those of a rope of shorter lay, " N " and " P," but again, if the considerable increase of strength of the rope be considered, the difference is hardly appreciable.

Unless the core be particularly large the outer strands bear on and cut each other. This accounts for the similarity shown by soft and hard core cables. When the core is too small some wires are cut through so far that they break, and, if possible, stand out from the rope. This is another cause of odd broken wires showing away from the main fracture, which is accompanied by low breaking strength.

A few torsion test results are given for a cable which had been in service for some time. The lowest number of twists correspond to wires which were of large diameter, " Q." Where a clip joins two thicknesses of cable to form a loop, only the outer wires of a strand are nicked, of which those which are abnormally large, " R," or are small, " S," are most severely treated. Available evidence from all sources supports the demand for wire which is uniform in all respects if a high degree of efficiency is to be secured.

The cores of the specimen ropes which were made to determine the effect of the length of the lay on the strength were carefully examined after the cables were broken in tension. The core of the " B " specimen with 2in. lay had the wires broken through at many places, in addition to the core being broken at the main fracture. The core of the 2¾in. lay sample was also fractured, but no other break of a single wire was discovered. It was impossible to trace the cores of the " C " ropes in which they were similar to the strands, but, as might be expected, the outer wires were least damaged in the cable with the longest lay.

The " C " specimens which had cores of lower tensile wire also presented unexpected features. The core of the shortest lay cable was damaged most, whereas the nicking of the outer strand wires was greater with a longer lay.

A long lay is less destructive by cutting both for the outer strands and core, with the exception of a rope which has a large core of softer wire, for which lengthening the lay does not appear to protect the outer strands.

The Efficiencies of Wire Cables.

Numerous cables have been analysed to determine their efficiencies. A tensile test was made of each wire used in the construction, sometimes the strands were tested, and in every case the breaking strength of the complete cable was found. There appears to be no necessity at present to give the individual test results, which would occupy a considerable space, but the important data is collected in tabular form attached.

TABLE 4.

THE EFFICIENCIES OF WIRE CABLES.

No.	Construction.	Lay of strand in rope. inches.	Sum of strengths of wires. lbs.	Breaking strength of strand. lbs.	Breaking strength of cable. lbs.	Efficiency of strand. per cent.	Efficiency of cable. per cent.	Remarks.
1.	5cwt. 4 × 7 × .010in.	—	636	149	590	94	92.6	Standard flexible cable.
2.	10cwt. 4 × 19 × .009in....	—	1142	335	1182	95	83.7	,, ,, ,,
3.	15cwt. 4 × 19 × .011in....	—	2136	507	1750	95	82.0	,, ,, ,,
4.	20cwt. 4 × 19 × .0120in.	1.2	3018	721	2730	95.5	90.5	Experimental.
5.	4 × 19 × .025in.	2.33	11936	—	10560	—	88.5	Rigging.
6.	4 × 19 × .0165in.	1.62	5955	—	5150	—	86.5	Standard kite balloon.
7.	4 × 37 × .018in.	2.29	13502	—	12070	—	89.4	Rigging.
8.	20cwt. 7 × 19 × .010in....	1.25	2790	389	2525	97.6	90.5	Standard flexible cable.
9.	25cwt. 7 × 19 × .011in....	1.35	3370	450	2930	93.6	87.0	,, ,, ,,
10.	7 × 19 × .022in., C	2.83	10846	—	13270	—	78.7	Experimental.
11.	7 × 19 × .023in., B.	2.75	18767	—	16140	—	86.0	Standard.
12.	7 × 7 × .0145in.	1.16	2777	—	2290	—	82.5	,,
13.	7 × 37 × .020in.	3.37	24020	3272	20400	95.4	84.9	,,
14.	6 × 19 × .026in. over 16 × .029in. × 1 × .019in.	2.65	22770	—	17500	—	76.9	Core of lower tensile wire.
15.	6 × 19 × .022in. over 16 × .026in. × 1 × .0175in.	2.1	17400	—	11880	—	68.2	,, ,, ,,
16.	,, ,, ,, ,, ,,	2.17	10775	—	12520	—	74.6	,, ,, ,,
17.	,, ,, ,, ,, ,,	2.79	16850	—	12740	—	75.6	Experimental tensile wire.
18.	,, ,, ,, ,, ,,	2.87	10970	—	12600	—	74.2	,, ,, ,,
19.	6 × 19 × .0172in. over telephone core ...	2.33	8905	—	8225	—	92.4	Experimental.
20.	6 × 19 × .025in. ,, ,, ...	3.1	20270	—	18370	—	90.7	Standard kite balloon.
21.	,, ,, ,, ,, ...	3.0	19470	3095	15400	95.2	79.3	,, ,, ,,
22.	6 × 19 × .0185in. ,, ,, ...	2.0	10532	—	8350	—	79.2	Experimental.
23.	6 × 19 × .022in. ,, ,, ...	2.08	14338	—	10890	—	75.9	,,
24.	6 × 19 × .0155in. over hemp core	—	6221	—	5110	—	82.1	Standard.
25.	6 × 19 × .023in. ,, ,, ...	2.71	15160	—	12270	—	80.9	Lang's Lay.
26.	11 × 7 × .0165in. over telephone core ...	1.75	5964	—	5450	—	91.4	Experimental.
27.	11 × 7 × .0165in. over hemp core	1.75	5558	—	5000	—	89.9	,,
28.	10 × 7 × .0165in. ,, ,, ...	1.92	5037	—	4595	—	91.2	,,
29.	9 × 7 × .0165in. ,, ,, ...	1.83	4535	—	3980	—	87.8	,,
30.	8 × 7 × .0165in. ,, ,, ...	1.58	4056	—	3630	—	89.5	,,
31.	7 × 7 × .0165in. ,, ,, ...	1.54	3503	—	3220	—	91.9	,,
32.	6 × 7 × .0165in. ,, ,, ...	1.66	3027	—	2755	—	91.0	,,

The efficiency of a strand is the strength of the complete strand divided by the sum of the breaking loads for the individual wires. The efficiency of a cable is taken as the strength of the complete cable divided by the aggregate strength of the wires.

The true efficiencies of the standard four and seven-strand cables range from 82 to 92½ per cent., Nos. 1 to 13. The six-strand ropes closed on telephone cores give equally good results, 19 to 21, but these are considered very fully later.

The use of a core of lower tensile wire appears to lead to a low efficiency, 14 to 18, but this is probably not true since the cables from the same manufacturer which have telephone cores are little better, 21 to 23. Some makers maintain a higher efficiency than others although the wire, lay and other characteristics which can be measured from the completed rope are the same.

Only one specimen of Lang's Lay rope was available for a complete analysis, and this gave a reasonably good efficiency in plain tension, although it is primarily intended for use over pulleys.

The multi-strand ropes, 26 to 32, are as satisfactory as those of simpler construction, and the 37 wire strand cable also gave a normal result.

In general, experimental ropes show somewhat higher efficiencies than can be maintained during regular manufacture.

For design purposes the completed rope has been assumed to have from 82 to 83 per cent. of the aggregate strength of the wires calculated from the mean diameter and mean breaking stress, or 85 per cent. if the minimum breaking stress be taken. The wire rope makers do not hesitate to accept these figures, which they consider to allow them sufficient margin to cover accidental circumstances, such as the wire running low in diameter or ultimate stress, because a minimum is specified for each. It should be noted that the efficiencies are similar for a large variety of construction. From 4 to 11 strands and from 7 to 37 wires per strand are represented here.

Varying Efficiencies of Cables made to the same Specification.

The specification for naval kite-balloon ropes was more severe than those for other cables because it was necessary to secure a high strength for the diameter and weight. The breaking stress of the wire was confined to the range 150 to 160 tons per sq. in., and its diameter had to be within the limits .0245 and .0255in. The lay of the strand in the rope was approximately 3in. The strength of the rope, 7.1 tons, called for 85 per cent. efficiency calculated on the mean diameter with a stress of 150 tons per sq. in.

It was foreseen that difficulties would arise in manufacture under the trying conditions which obtained during the war, especially so because the makers had no experience of closing cables on telephone cores. Routine tests were made, and in some cases a more complete analysis was made by making a tension test of each wire. It was hoped in this way to obtain data from which some of the factors which affect the efficiency could be determined.

The wire is drawn to a high tensile strength and in consequence is not very ductile. Its plastic is usually less than the elastic elongation at fracture. In this respect this wire is not appreciably different from that of lower tensile strength which is commonly used for commercial ropes. Reference has been made to the nicking or cutting which takes place when there is relative movement of wires which bear on each other, and wire ropes, usually of special construction, have been used solely for cutting purposes.

Here, again, the tests should be divided into two classes, firstly those which were made to answer definite queries, and secondly the analysis of cables which

were either abnormally weak, or strong, or presented some other peculiarity. The former are dealt with first.

An early cable, " B " 131, was weaker than those usually supplied by the same maker and had an efficiency of 77.5 per cent. It contained a number of wires of very high tensile strength two giving about 200 tons per sq. in. At first it was thought that the abnormally strong wires had insufficient ductility and broke prematurely. A length of rope was loaded up to six tons tension when about 20 wires had been heard to break, the first failing at 5.7 tons. The broken wires were traced along the rope and were tested on the 4ft. length which had not been stressed beyond the grips, with the following results :—

	Strand 1.				Strand 3.	
Diam., ins.	.0259	.0244	.0245	.0250	.0242	.0248
Turns in 8in.	68	78	111	87	26	101
Load, lbs....	165	167.5	166.5	168	164.5	167
Stress ton/sq. in. ...	140	160	158	153	160	154

	Strand 4.			Strand 5.				
Diam., ins.	.0256	.0253	.0246	.0254	.0249	.0256	.0258	.0250
Turns in 8in.	89	72	47	44	65	95	99	75
Load, lbs.	171	175.5	164	174.5	167.5	161	172.2	166
Stress ton/sq. in. ...	148.5	156	154	154	153.5	140	147	151

Diam., ins.	.0252	.0254	.0251
Turns in 8in. ...	99	15	89
Load, lbs.	142	166.5	167.5
Stress ton/sq. in. ...	127?	147	151

Strands 2 and 6 had no wires broken.

It was noted that only wires from the outer twelve of a strand were broken where the strands bedded together; five were outside, but most were within the limits of the specification. It was thought that the strong, hard wires cut through the others as the strands bedded together under the tension, because the nicking could be detected.

Although the diameter of the telephone core had been checked, it was probably too small, and the nicking of the wires would have been less, and the strength of the cable greater in consequence, if the core had been of rather larger diameter.

If the core be small, and the strands bed tightly on each other, the presence of hard wires will somewhat intensify the cutting, but the core should be of sufficient diameter to keep the pressure between the strands so low that the wires are not appreciably weakened thereby.

The Bearing of Core Diameter on the Strength of a Cable.

Some cables were weakened by the cores being too small. An attempt was made to discover whether this defect caused the rope to lose its circular form under tension. A rope of normal strength varied in diameter at one section only .001in. up to 8,000lbs. tension, which became .002in. at 12,000lbs. Another example from the same maker, but half a ton weaker, showed .003in. difference at 9,000lbs., which reduced to .001in. at 12,000lbs. It is a difficult matter to obtain an accurate measurement of the diameter of the wire rope, so that the method is not simple in operation, and these results do not show any difference between a strong and a weak cable.

It is worthy of notice that when a core was thought to be small, and it was

left to the ropemaker to increase the diameter, the amount of packing added was not sufficient to increase the tensile strength of the cable very materially.

In one case two samples were closed for comparison, one on the bare core, and another with jute threads over the core to increase its effective diameter. The strengths were 6.95 to 7.0 tons respectively, each less than the specified breaking load.

The next comparative tests have a bearing on the effect of uniformity of the wire as well as on the diameter of the core of the cable. The wire as received at the time the samples were made was too variable, much of it being outside the limits specified. Two samples were made of wire taken at random, and two more from wire which was selected as the result of further tests. Each of two pieces of core had half its length overwound with lappings of cotton. One core was closed in a cable made of ordinary wire, and for the other the selected wire was used. Tension tests were made of samples cut from either side of the junction of the covered and uncovered core, with these results :—

Selected wire core not covered, .389in. diameter, broken at 7.0 tons.
Selected wire core cotton covered, .399in. diameter, broken at 7.02 tons.
Ordinary wire, core not covered, .389in. diameter, broken at 7.12 tons.
Ordinary wire, core cotton covered, .400in. diameter, broken at 7.23 tons.

The maximum diameter for the rope was .390in., from which it could be claimed that the uncovered core was large enough, because cables of this size gave considerably more than the specified breaking load. The fact that the cables were weak gave the impression that the cores were small. Increasing the core diameter had little effect on the strength of the rope.

The importance of the fact that the use of selected wire led to weaker cables should not be overlooked.

In another instance a ropemaker prepared three samples, one on a hemp core which he considered to be of the correct size for this cable, another on a telephone core, and a third on the telephone core with ten jute threads run in to increase the effective diameter. The strengths of the ropes were :—

(1) With jute heart, diameter .390in., broken at 6.18, 6.04 tons.
(2) Telephone core, diameter .389in., broken at 6.20, 6.36 tons.
(3) Telephone core and 10 jute threads, diameter .405in., broken at 6.96, 7.60 tons.

The rope diameters indicate that the jute heart and telephone core were sufficiently large, and that the latter was of the correct size as judged by the manufacturers. The breaking strength with the telephone core was rather higher than with the jute. The addition of the ten threads was excessive and led to an open cable which was much too large, but it certainly improved the strength of the rope. In cases (1) and (2) the wires were broken first where the strands touched each other. The diameter of these wires for (2) were :—.026, .0262, .0255, .0257, .0252, .0272, and .0273, which appears to show that the larger wires stand out from the strand and are cut through first.

The photograph, Fig. 1, shows that wires were broken all over the cables (1) and (2), and an absence of this feature in the case of (3).

The true facts of this case were somewhat complex. The telephone core was large enough for the normal rope, but the average size of the wire was somewhat high and required a correspondingly large core, but not nearly so much so as was provided in the sample (3). Tests of later ropes from the same source have shown that the low strength was largely due to the procedure during the actual laying up, and in no case was a very high efficiency recorded.

The effect of core diameter on the strength of ropes from different manufacturers was checked in another way. It was found that no useful information was given by measurements of the diameters of cores taken from the cables. The

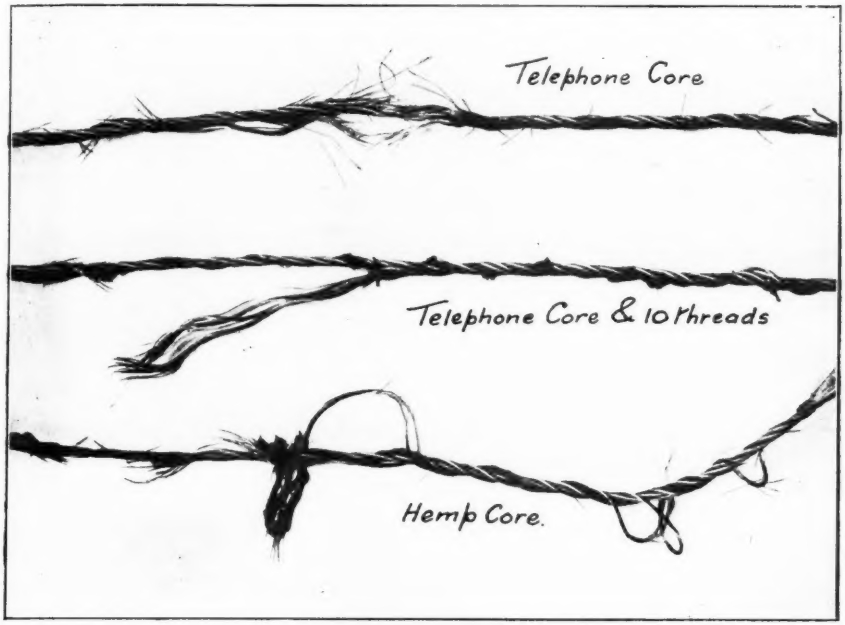

Fig. 1.

cores were numbered consecutively and were supplied to different ropemakers to be closed into cables which were given the numbers of the cores. Batches of the samples are arranged in order, with the breaking load and maker, to include some which were below the required breaking strength.

Rope Numbers.	Maker.	Breaking Strength. Tons.	Rope Numbers.	Maker.	Breaking Strength. Tons.
595	B	7·1	1040	B	7·9
596	B	7·55	1041	B	7·8
597	L	7·30	1042	B	7·55
598	L	7·34	1043	S	6·98
599	L	6·98	1044	S	7·2
600	L	7·08	1045	S	6·28
601	L	7·06	1046	S	6·69
602	W	6·78, 6·53	1047	S	6·39
603	W	6·78	1048	N	7·12
604	W	7·3, 7·33	1050	N	7·04
605	W	6·5, 6·8	1051	N	6·75, 6·95
606	W	6·62, 6·39			
607	W	7·12	1096	N	7·07
608	W	6·68, 6·5	1097	S	6·15
609	L	7·11	1098	S	6·40
610	L	6·99	1099	N	6·6
611	L	7·07	1100	B	7·29
612	L	7·33	1101	N	6·95
613	L	7·0			
614	L	7·2			
615	A	7·14			

The cables supplied by " L " were very consistent for strength, averaging about 7.3 tons, until those shown in the first set. Here the strengths were somewhat reduced, but did not fall below 6.98 tons, the cause of the weakness being that the cores were supplied below the specified diameter. The ropes made by " W " were affected much more seriously by this cause.

The samples in the second set from the manufacturer " N " were much lower in breaking strength than was usual, and include, with the last set, the only " N " cables which were below the 7.1 tons required. From this it can safely be concluded that the cores were small, yet the ropes from " B " were satisfactory, and those which were closed on intermediate cores by " S " were generally weak. The third set presents similar features, a " B " rope is satisfactory, " N " cables are below strength, and also those from " S " are the weakest of all.

It is clear that if the core be too small the strength of the cable is low, but the loss of efficiency varies with the maker, being least from " B," " L " and " N," and much more from " S " and " W."

Another example is afforded by cables of a different type. A comparatively small core is required if only four strands be used, and by an oversight in the works some of these cables were closed without any core at all. Two samples were then made, one half of each with a core and the remainder without. The tensile strengths were :—

Cable.	Strength with core.	Strength without core.
4 × 19, 10cwt.	1455, 1435lbs.	1325, 1380lbs.
4 × 19, 5cwt.	670lbs.	660lbs.

Apparently the core is more important for the larger cable, and there is slight evidence to support the conclusion from the kite-balloon cables that a small core gives rise to a variable as well as a weak rope.

Differences of Strength along the same Cable.

The breaking strengths of adjacent pieces of cable have been quoted in numerous instances, from which it is possible to estimate the variations that are likely to be met with. The method of testing might introduce an unknown factor which is greater than that associated with a tension test of a solid metal specimen. There is a tendency on the part of certain manufacturers to emphasise this difference of strength in order to excuse the low test results of cables which are met with occasionally. A few representative strengths are given as obtained by the ropemakers and by independent tests, the former with the cable held in wedge grips and the latter socketted. The portions tested were probably about 20 feet apart in the rope. The differences are due not only to variation in the rope, but also to the method of securing the ends, calibrations of the testing machines, speed of loading and accuracy in measuring the load. The works method is likely to give high results through rapid straining and overrunning the balance weight.

Rope number	428	435	431	1122	1128	1131	1129	626	1054	635	1056	1138
Maker's strength	7.42	7.5	7.2	7.95	6.95	7.3	7.65	7.1	7.35	7.35	7.8	6.9
Strength at Finsbury	7.2	7.6	7.4	8.02	6.85	7.26	7.57	7.26	6.95	7.42	7.62	7.12

Rope number ...	2000	2002	2003	2018
Maker's strength ...	8.05	7.7	7.45	8.05
Strength at Finsbury	7.8	7.4	7.3	7.4

The last one is given to show the largest difference which was only found very occasionally, and which undoubtedly did not represent a true variation along the cable.

Greater differences have been found between the two ends of kite-balloon cables, 3,000ft. long, closed over telephone cores, thus :—

Rope number	B131	B128	B150	B154	A163	A164	A165
Strength at finishing end ...	6.75	6.9	6.8	6.7	6.53	6.78	6.37
Strength at starting end ...	7.1	7.35	6.8	6.7			
	7.05	7.35	6.75	6.9	7.02	6.45	7.24

In general the starting end of a rope is stronger than the finishing end, but there are exceptions to this rule. The difference cannot be attributed to any single cause.

Finally, the analyses of kite-balloon cables which were made from time to time, are tabulated, and include some normal, but also many examples of ropes which were particularly strong or weak. The data is collected from a very large number of tests, 114 wires from each cable having to be broken separately in tension.

The strand efficiencies are :— " B " .922 to .962, " A " .905 to .965, " N " .948, " S " .96 to .97, " W " .945 to .977. Little can be deduced from the results except that it is clear that the weakness of " S " and " W " ropes is not due to the stranding.

The cable efficiencies are :—" A " .72 to .89, " B " .775 to .92, " N " .80 to .82, " S " .66 to .85, " W " .76 to .85. In many cases " N " ropes gave considerably higher efficiencies than those included here. The results have been treated in several different ways to discover whether the large variations can be accounted for. It has been shown already that a small core, or a number of wires of large diameter, reduces the efficiency. The most useful information is likely to be derived from good ropes, because all the essential conditions must be fulfilled to give a high efficiency, or rather, none can be unobserved to a sufficient degree to spoil the cable. On the other hand, the failure to meet one of the several requirements is sufficient to lower the efficiency. The strengths of the wires are studied here, and even if these be entirely satisfactory, yet another factor, such as a small core or poor ropemaking, might weaken the cable.

The strengths of the individual wires in several cables have been plotted, and the best cables consist of wires which break under widely different loads. " B " ropes gave high efficiencies when made of wires which had a range of breaking stress from 140 to 180 tons per sq. in.; but few manufacturers can, in general, achieve this result. The " L " ropes were the most consistent, and it is unfortunate that only one was analysed. Most of the wire was kept in the range 140 to 160 tons sq. in. The same stress range applies to the best " A " cables. The " S " and " W " ropes seldom had high efficiencies, and although there is some indication that uniform wire is best, the evidence is by no means clear.

TABLE 5.

ANALYSIS OF KITE BALLOON CABLES.

No. of cable.	Sum of strengths of wires in strands. lbs.	Total lbs.	Strength of strands. lbs.	Strength of cable. tons.	Strength of cable. lbs.	Efficiency of cable from strand.	Efficiency of cable from strand.	Efficiency of cable from wire.
B128 ...	3214.5 3282		3140 3130					
	3235.5 3302	19783	3145 3280	6.9	—	.958	.816	.782
	3320 3429		3080 3175					
			18950					
A167 ...	3279 3345.5		3040 3090					
	3348 3277	19957	3210 3110	7.26	16260	.940	.867	.815
	3292 3416		3250 3050					
			18750					

TABLE 5 *(continued).*

No. of cable.	Sum of strengths of wires in strands. lbs.	Total lbs.	Strength of strands. lbs.	cable tons.	lbs.	Efficiency of cable from strand.	Efficiency of cable from strand.	Efficiency of cable from wire.
B131 ...	3284 3265 3236 3232	19526	3080 3080 3090 3010 3090 2995 18345	6.75	—	.940	.824	.775
A165 ...	3234 3322 3380 3301 3351 3206	19854	2895 — 2950 3010 3130 3030 18018	6.37	14270	.907	.792	.719
A199 ...	3342 3321 3313 3331 3318 3399	20024	3145 3090 2975 3100 3110 3080 18500	6.8	15240	.923	.824	.761
S15 ...	3261 3339 3334 3295 3307 3333	19869	3175 3150 3190 3200 3160 3210 19115	6.68	14970	.962	.782	.754
N196 ...	3432 3448 3345 3420 3454 3430	20529	3225 3290 3175 3310 3275 3220 19475	7.52	16870	.949	.866	.821
Large core..	3365 3366 3383 3359 3394 3366	20203	3130 3150 3090 3060 3190 3090 18710	8.2	—	.926	.981	.909
A165 ... Starting end	3281 3366 3320 3328 3215 3351	19861	3060 3165 2935 3010 2925 2890 17985	7.24	—	.905	.901	.816
L264 ...	3145 3218 3142 3138 3161 3166	18970	—	7.4	—	—	—	.875
S22 ...	3355 3286 3327 3266 3364 3273	19871	—	7.16	—	—	—	.807
B218 ...	3210 3142 3171 3209 3209 3145	19086	3060 2885 3015 2940 2980 2995 17875	7.28	—	.936	.912	.855

TABLE 5 (*continued*).

No. of cable.		Sum of strengths of wires in strands. lbs.	Total lbs.	Strength of strands. lbs.	cable. tons.	lbs.	Efficiency of cable from strand.	cable from strand.	cable from wire.
A221	...	3131 3061 3130 3151 3086 3146	18705	3005 3060 3000 2995 2990 3010 18060	7.42	—	.965	.920	.889
A259	...	3202 3264 3255 3224 3197 3201	19343	—	7.16	—	—	—	.829
B301	...	3271 3315 3346 3323 3354 3251	19860	3135 3055 3140 3185 3245 3020 18780	7.95	—	.945	.949	.897
B315	...	3363 3376 3372 3346 3321 3334	20112	3050 3190 3285 3055 3115 2860 18555	7.93	—	.922	.957	.883
S1018	...	3277 3280 3269 3225 3235 3203	19489	—	7.13	—	—	—	.820
S1014	...	3281 3271 3282 3314 3265 3223	19636	—	7.44	—	—	—	.848
S1016	...	3249 3165 3304 3299 3273 3198	19488	—	6.93	—	—	—	.797
A260	...	3284 3367 3313 3341 3327 3272	19904	—	6.75	—	—	—	.760
B303	...	3283 3415 3236 3353 3176 3305	19768	3155 3150 3170 3205 3175 3160 19015	8.14	—	.962	.958	.922
S1045	...	3236 3262 3221 3158 3194 —	19285	—	6.17	—	—	—	.717
S1105	...	3286 3470 3291 3278 3321 3248	19891	—	5.84	—	—	—	.658
S1097	...	3280 3268 3210 3252 3252 —	19514	—	6.15	—	—	—	.706

TABLE 5 (*continued*).

No. of cable.	Sum of strengths of wires in strands. lbs.	Total lbs.	Strength of strands. lbs.	Strength of cable. tons.	Strength of cable. lbs.	Efficiency of cable from strand.	Efficiency of cable from strand.	Efficiency of cable from wire.
S1106 ...	3250 3311 3292 3263 3282 3318	19716	—	6.34	—	—	—	.720
N1114 ...	3144 3207 3170 3254 3170 3142	19087	3015 2915 3010 3085 3100 2970 18095	6.79	—	.948	.840	.797
A618 ...	3283 3257 3326 3330 3201 3288	19685	Wire brittle	7.16	—	—	—	.816
S86 ...	3287 3182 3181 3242 3173 —	19278	3090 3130 3070 3090 3090 3195 18665	6.10	13660	.968	.732	.709
S90 ...	3389 3240 3283 3333 3272 —	19820	3235 3130 3205 3230 3120 3315 19235	6.30	14110	.970	.734	.712
S92 ...	3325 3266 3297 3352 3322 —	19874	3210 3080 3210 3205 3190 3175 19070	6.35	14220	.960	.746	.716
W605 ...	3221 3208 3166 3201 3180 —	19171	2975 3060 3005 3070 2950 3045 18105	6.50	14580	.945	.805	.761
W606 ...	3241 3230 3225 3177 3223 —	19315	3180 3150 3145 3130 3115 3160 18880	6.62	14820	.977	.786	.767
W555 ...	3134 3239 3292 3182 3124 —	19165	2910 3130 3145 3040 3085 2895 18205	7.30	16350	.950	.899	.853
W1286 ...	3178 3195 3236 3214 3198 3193	19214	—	7.16	—	—	—	.835
W1287 ...	3260 3255 3190 3214 3263 3183	19365	—	6.92	—	—	—	.802

The strengths of the six complete strands were plotted for a number of ropes, and there is little doubt but that uniformity in this respect is desirable.

Examination of the broken ropes showed that there were no odd wires standing out away from the fractures of the " L " specimens, but this feature was common with the "S" cables. Of the latter 1,045 had a small telephone core, and the same cause accounts for N1050 and 1052 being included. All the " S " ropes, 1105 to 1110, were weak, undoubtedly because the strands bedded tightly on each other.

Load-elongation curves for the cables, on a length of about 27 inches, show that the yield is less than the elastic extension at fracture. The former was appreciable for the " A " samples which met the specification, and also for the " L " and " N " specimens, but it was smaller for the " B " cables, although these were strong enough. The " S " test lengths had a low elastic limit when the ultimate strength was low. The curves give little information concerning the requirements for a high efficiency, because sometimes a strong cable has a high elastic limit, or, alternatively, the yield point is normal and the curve is continued further to show a greater non-elastic extension.

Autographic load-extension curves for single wires prove that the yield elongations are less than those for the cables, part of the latter being caused by the straightening of the strands. A set of sample wires from Messrs. E. and A. Smith varied in diameter from .020 to .030in., and in breaking stress from 100 to 170 tons per sq. in., but gave approximately the same yield strain at fracture, which in all cases was small. A very brittle wire gave a straight diagram to the breaking point. These tests indicate that wires taken from naval kite-balloon cables were rather more ductile than the Smith samples, and were very similar, although they were supplied by different wiredrawers, but they were inferior to some of the .023in. diameter wire used for the early ropes.

Conclusions.

An end shock produces an additional tension in a cable which must be included in the estimate of the working load.

The strength of a rope is increased if it is subjected to prolonged shock and vibration whilst under a high tension.

Seven-strand are as efficient as six-strand cables with fibre cores, and are stronger for a given diameter and weight.

Cables can be made as efficient of wire which has a breaking stress of 160 tons per sq. in. as of lower tensile wire.

Low efficiency of a cable is usually accompanied by large differences in strength from point to point.

Odd wires break during a tension test of a rope, apart from the main fracture, (1) if the wires be abnormally weak, (2) or of too large diameter, (3) or brittle, (4) but the most common cause is that the core is too small, or too soft, and the strands cut each other.

One or two of the outer wires of a 19-wire strand are slightly nicked in the completed rope, but not sufficiently to affect their tensile strengths.

Exceptionally small or large wires are damaged most where a clip is attached to a rope.

The starting is usually stronger than the finishing end of a long cable, and consequently short, experimental lengths usually have higher breaking strengths than can be maintained during regular manufacture. A maximum difference of 13 per cent. was recorded between the ends of a rope 3,000 ft. long.

A series of cables showed a maximum difference in strength of 5 per cent. for the same rope when the test pieces were cut within a few feet of each other.

Load-elongation curves for single wires and for complete cables show only a small amount of yield at fracture, always less than the elastic elongation.

The efficiency of 19-wire strand supplied by several manufacturers varied from 90 to 98 per cent.

The efficiency of a 6 x 19 cable, made under difficult war conditions, varied from 77 to 92 per cent. from the best ropemakers, and in the worst cases fell as low as 66 per cent.

The efficiency of a variety of cables from good makers varied from 82 to 92 per cent. These cables consisted of from four to eleven strands of from seven to thirty-seven wires per strand.

Cables may be specified to give 82 per cent. of the sum of the strengths of the individual wires, calculated from the mean diameter and breaking stress.

In order to secure the best efficiency the following conditions should be observed :—

(1) The core must be of sufficiently large diameter and hard enough to prevent the outer strands cutting each other.

(2) The lay of the strand in the cable must be sufficient. Successful results have been obtained with the strand laid at 15½ degrees to the axis of the rope. The strength of a cable should be greater as the lay of the strand is lengthened. No increase was realised in the case of cables with cores of lower tensile wire. An increase of the lay of a rope, closed on a wire core of given diameter, relieves the core of tension, reduces the pressure of the strands on each other, and increases the pressure of the strands on the core. But the nicking on the core wires is reduced because the relative movement of the strands on the core is smaller.

(3) It is best to build up both strand and cable of wire of approximately the same diameter and breaking stress. The breaking stress of the wires cannot, in general, be kept within a closer range than 30 tons per sq. in., probably on account of variations of strength from point to point along a wire.

(4) The strands should be of as nearly equal strength as possible.

The products of some ropemakers are less affected than those of others by a divergence from the conditions set out above. If a core be too small the cable closed on it is weak, but to an extent which depends upon the maker. Cables have been made by certain firms of variable wire, but nevertheless have given an excellent efficiency.

Cables made by different manufacturers, with all but one of the measurable quantities of the completed rope the same, have unequal strengths. This results from matters of detail during the manufacture, particularly during the closing of the rope.

Connections.

End connections are commonly formed on cables by looping to form an eye and splicing, or the splicing is replaced by a wire serving which is soldered after it is put on, or by the use of some form of clip to hold the two thicknesses of rope together. Another method is to open out the wires in a taper socket and to hold them by running in an alloy of the solder class. Fig. 2 shows three forms of clip and Fig. 3 gives several views of sockets.

Spliced eyes do not give the full strength of the cable in simple tension, because fracture usually starts at the end of the splice at a tension which (with the best made splices) is 95 per cent. of the breaking strength of the rope. Vibration or shock emphasises the weakness, and losses up to 25 per cent. have been

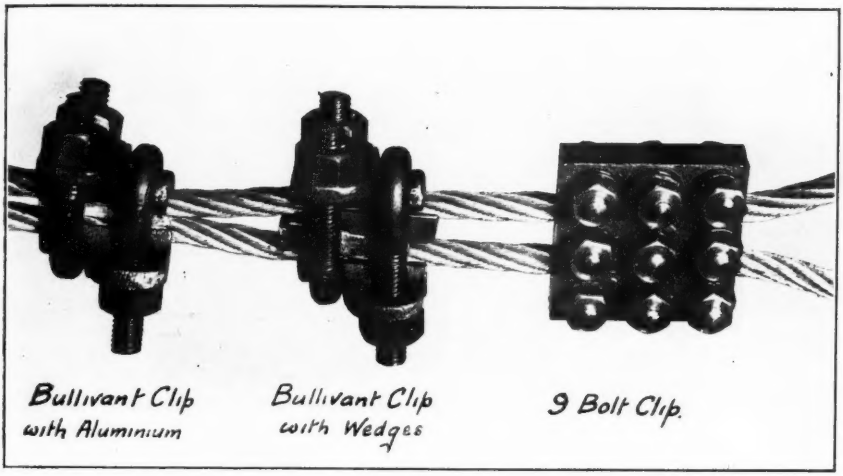
Bullivant Clip
with Aluminium
Bullivant Clip
with Wedges
9 Bolt Clip.

Fig. 2.

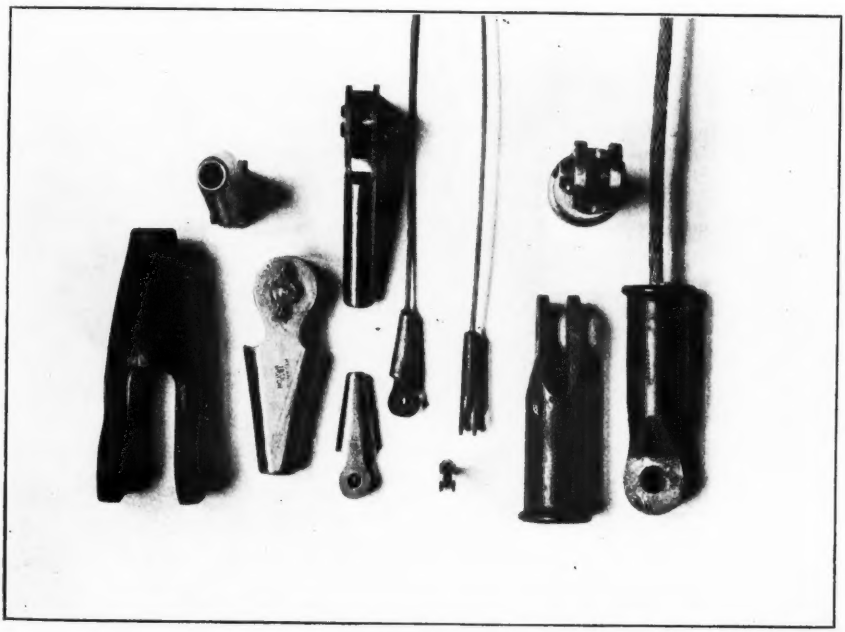

Fig. 3.

recorded after six hours lateral vibration at three-quarter load. A wire is weakened by lateral pressure when it is under tension, and if the pressure be exerted by another wire and relative motion takes place, there is further weakening by the wires chafing and cutting each other.

Correct socketting allows the full strength of the cable to be realised under all conditions, and the rope breaks clear of the socket when under test. Clips do not give such a good result, and are more severe on the cable if they be short, especially on larger ropes. Clips also have the disadvantage that they require to be tightened as the tension increases, or at intervals if a high tension be accompanied by shocks. A cable had its diameter of 8.4mm. reduced three per cent. under a tension of 7,000lbs.

The tension which can be taken without slipping is in general increased by the use of more clips, but two clips cannot be depended upon to carry twice the load supported by one. Grooving the clips to fit the cable leads to a large increase of the load carried.

The gripping power of clips is considerable and for general use, when the tension on the rope is a comparatively small fraction of its breaking load, they are convenient fittings and lend themselves to a rapid and exact adjustment of length. The Bullivant type is preferable because the nine bolts take too long to tighten, and the nuts are so close together that a tube spanner must be used. If the joints are accessible, so that the nuts can be retightened with the rope under tension, the importance of one objection to the use of clips is greatly reduced.

Experiments on Bullivant clips fitted with wedges, Fig. 2, were most encouraging, but it was necessary to keep the angle of the wedges small or they did not slide on each other and maintain the grip on the rope. A single clip of this type, with wedges one and a half inches long, carried more than four tons tension, without tightening, on a cable which broke at 5.3 tons. Two clips were employed when the test was continued until the rope was broken under plain tension, and although the clip localised the fracture, the greatest reduction of strength was only 5 per cent. for three tests. One plain and one wedge clip appeared to be the best arrangement.

The damage caused by the clips was not very serious even under continued shock and vibration combined with tension for five hours. The loss of strength was only about the same as under plain tension.

The following instructions were drawn up for the making of bound and soldered joints in wire rope, and each point can be justified by a considerable volume of experimental evidence:—

Ordinary service solder may be used. (Tinmans.)

The binding wire should be tinned, but galvanised wire may be used in an emergency if tinned wire be not available.

Baker's Fluid must be employed as the flux.

The gauge of the serving wire and the length of the joint are given in the table below.

Greasy cable should first be cleaned with paraffin or the like. The cable is looped into the required position and the joint is tightly served for the length and with the gauge of binding wire specified. A piece of wet waste or rag is wrapped around the standing part of the rope for a short distance from the end of the joint. This waste should be wetted if it dries during the soldering. The joint is next wetted thoroughly with Baker's Fluid, and solder is applied by means of a soldering iron until it can be seen to run through the joint. On no account should heat be applied in any other way, as by a flame. After soldering the binding wire should be cleaned with a neutral grease, or tallow, which will melt and clear away any excess of the flux.

This type of joint should be avoided in places where the cable is subjected to excessive vibration, either lateral or longitudinal.

These joints are too large and clumsy for larger than four-ton ropes.

DIMENSIONS OF BOUND AND SOLDERED JOINTS.

Rated Breaking Strength of Cable.	Gauge of Binding Wire.	Length of Joint.
5 cwt.	26	$\frac{3}{4}$ inch.
10 ,,	26	$1\frac{1}{4}$,,
15 ,,	22	$1\frac{3}{4}$,,
20 ,,	22	$2\frac{1}{4}$,,
25 ,,	22	$2\frac{1}{2}$,,
35 ,,	20	3 ,,
45 ,,	20	4 ,,
60 ,,	18	$4\frac{3}{4}$,,
70 ,,	18	5 ,,
75 ,,	18	$5\frac{1}{2}$,,
80 ,,	18	6 ,,
90 ,,	18	$6\frac{1}{2}$,,
100 ,,	18	$7\frac{1}{2}$,,

These lengths of joints are double those required just to break the cables, based on the lowest test results from a wide range of experiments.

Instructions were also prepared for the procedure in socketting, as under:—

It is understood that the cable is composed of more than one strand. It is not possible to guarantee that socketted straining cord will in all cases give the full strength of the cable with the sockets adopted. The end of the cable will be bound. Note the place on the cable which will come at the end of the socket and put on a binding there. This serving may be of binding wire, but for the smaller ropes tarred twine is to be preferred ($\frac{1}{4}$ inch long for 15 cwt. cable, $\frac{1}{2}$ inch for 7 tons).

Thread the cable into the socket and spread the wires.

Bind the cable with asbestos cord *for a short distance* from the small end of the socket to protect it from heat.

Heat the socket gently at the eye end until it can just be touched by the finger at the small end. Be extremely careful not to overheat the cable. Put powdered resin into the hot socket and pour in melted solder. Clear out any excess solder to allow sufficient clearance below the pin.

These instructions were intended to apply to airship rigging with cables up to the 20 cwt. size. For larger ropes a harder socketting metal must be used or the rope draws out by shearing the solder. Babbit metal No. 1 has been found satisfactory and has the advantage that it is readily procurable.

On the whole the efficiency of eye splices increases with the size of the cable. Tests have given 75 per cent. for 15 cwt. and 87 for 65 cwt. ropes, but the results are irregular, a 17 cwt. specimen giving 82 and a 50 cwt. 78 per cent.

Splices are also used to join two lengths of cable. A short splice, 55 cable diameters long, had an efficiency of 82 per cent., whereas the long splice should never give less than 90 per cent. efficiency reckoned on the actual breaking strength of the rope.

The strength of a cable looped over a pin is of interest. Four strand, 15 cwt. flexible cord, looped on a pin and both ends pulled, broke at 1.28 times the strength of the cable on a $\frac{3}{4}$ inch pin and 1.67 over a pin of 2 inches diameter. The corresponding ratios for 15 cwt. straining cord were 1.56 and 1.93.

The elongation of wire cables under tension was given a considerable amount of attention. In all cases the test length was twenty feet. The first experiments were made on cables which were not free to rotate at either end. When the loads and elongations are plotted the points lie very fairly on straight lines, and it is therefore possible to calculate an equivalent modulus of elasticity for these ropes, for which the stress is taken as the load divided by the product of the number and the sectional area of the wires. The moduli for the ropes are about half that of the steel, the calculated results being :—

7 × 37 × .020in., 8 tons,	equivalent	modulus	of	elasticity,	6480	tons/sq. inch.
6 × 19 × .025in., 7.1 tons,	,,	,,	,,		6370	,, ,,
6 × 19 × .0172in., 3.25 tons,	,,	,,	,,		7040	,, ,,
11 × 7 × .0165in., 2.25 tons,	,,	,,	,,		6870	,, ,,
7 × 19 × .011in., 25 cwt.,	,,	,,	,,		7370	,, ,,
7 × 19 × .010in., 20 cwt.,	,,	,,	,,		7850	,, ,,
4 × 19 × .011in., 15 cwt.,	,,	,,	,,		7790	,, ,,
4 × 19 × .0092in., 10 cwt.,	,,	,,	,,		7600	,, ,,
4 × 7 × .0105in., 5 cwt.,	,,	,,	,,		10100	,, ,,

Generally speaking the modulus is somewhat higher for the smaller cables.

Experiments were made with many cables when the tension was applied through a ball bearing swivel which allowed the specimen to twist under the load. Under these conditions the elongation is not usually proportional to the tension, and the hysteresis is observed if measurements are made as the load is reduced, because there is a permanent set in the cable.

The elongation of a free ended cable is considerably greater than that with a fixed end. A modulus of elasticity cannot be calculated from the former case, therefore the elongations under both conditions are tabulated at the same load, for ease of comparison.

Cable.	Tension.	Elongation. A. With fixed ends.	Elongation. B. Swivel ends.	Ratio. B/A.
7 × 37 × .020in., 8 tons ...	3.0 tons	1.36 inches	3.56 inches	2.62
6 × 19 × .025in., 7.1 tons ...	3.0 tons	1.85 ,,	4.57 ,,	2.47
6 × 19 × .0172in., 3.25 tons ...	1.5 tons	1.93 ,,	4.39 ,,	2.28
4 × 19 × .0172in., 2.25 tons ...	2500 lbs.	1.92 ,,	2.95 ,,	1.54
11 × 7 × .0165in., 2.25 tons ...	1.0 ton	2.17 ,,	6.32 ,,	2.92
4 × 19 × .011in., 15 cwt. ...	500 lbs.	0.93 ,,	2.10 ,,	2.26
4 × 19 × .0092in., 10 cwt. ...	400 lbs.	1.13 ,,	1.89 ,,	1.67
4 × 7 × .0105in., 5 cwt. ...	120 lbs.	0.51 ,,	0.82 ,,	1.61
6 × 19 × .023in., Lang's lay ...	1.75 tons	1.25 ,,	13.4 ,,	10.7

The ratio of the elongations is approximately from 2.3 to 2.6 to 1 for the large cables, but it is usually smaller for the four-strand specimens. The eleven-strand cable has a normal modulus of elasticity, but the ratio here is high, namely, 2.92. The tremendous elongation of the Lang's lay cable, when the ends are free to rotate, is a most noticeable feature of the table. The additional permanent set at the second loading is comparatively small in all cases.

Measurements of the torque which must be applied to fix the ends of a cable show that it is two-thirds of that which would be calculated from the dimensions of the rope before it is stressed. The difference is accounted for by the reduction of diameter and lengthening of the lay under load.

The repeated bending of cables over pulleys is such an important subject, and so much data is available, that it is regretted that it cannot be adequately dealt with here.

THE DESIGN OF SPARS WITH OFFSET PIN JOINTS.*

BY HARRIS BOOTH, TECHNICAL ADVISER TO THE BLACKBURN AEROPLANE CO.

The method here described has some advantages over the present standard method of designing with continuous spars. Firstly, it gives lighter spars by working as many points as possible up to the elastic limit. Secondly, it is far quicker to use owing to the necessary formulæ and processes of computation being more manageable and to the fact that practically each bay can be designed separately without affecting the others. Thirdly, the roughing out and the final checking are doné with the same set of formulæ, whereas, if the usual type of spar construction is adopted, it is necessary to use different methods for the preliminary and final design.† Fourthly, the accuracy of the work is not affected by the supports getting out of line when the whole structure deflects under load, a serious error in the older method being thus avoided. Fifthly, the short spar lengths given by the present method reduce the temptation to resort to splicing, on the undesirability of which practice some remarks will be found in §18 (6) hereunder.

There is, on the other hand, the disadvantage that the fittings are heavier than in the older type of design, a fact which partially discounts the weight saving due to lighter spars.

A reader wishing to make practical use of the method here set forth should start by reading §18, from which he will see that unless he wishes to verify the mathematics he need not read much of the rest. He would be well advised, however, to skim through the whole paper in order to see how the various symbols are defined, and particularly how their signs are related to the sign of w.

1. The Bending Moments in a Bay of a Spar Carrying a Compression and a Distributed Load when the End Bending Moments are known.

Let l be the length of the bay, I the moment of inertia and E the coefficient of elasticity. Let P be the compression in the centre line of the spar before deflection, w the upward acting distributed load per unit length and M the bending moment, reckoned positive when the top of the spar is in compression. Let x be the length co-ordinate along the spar from the left hand end and y the upward deflection. Let M_1 be the value of M at $x = 0$ and M_2 the value of M at $x = l$. Let S be the downward acting force applied by the abutment to the spar at the left hand end of the bay. Let x_1 be the value of x at a point where it is proper to splice the flanges of the spar and x_2 the value of x where it is proper to splice the web.

Then :—

$$EId^2y/dx^2 = M = M_1 - Sx + \tfrac{1}{2}wx^2 - Py$$

$$\therefore EId^2y/dx^2 + Py = M_1 - Sx + \tfrac{1}{2}wx^2$$

The solution of this is :—

$$y = a\cos px + b\sin px + M_1/P - EIw/P^2 - Sx/P + wx^2/2P$$

$$\text{where } p = \sqrt{(P/EI)} \quad . \quad . \quad . \quad . \quad . \quad (p)$$

and a and b are constants of integration.

$$\therefore M = EIw/P - P(a\cos px + b\sin px) \quad . \quad . \quad . \quad (M)$$

* Attention is directed to Patent Number 135,312.

† See "Aeroplane Structures," by Pippard and Pritchard.

the angle, of course, being in radians.

Now $M = M_1$ at $x = 0$ and $M = M_2$ at $x = l$

$$\therefore\ a = EIw/P^2 - M_1/P \qquad . \quad . \quad . \quad . \quad (a)$$

$$\text{and } EIw/P^2 - M_2/P = a\cos pl + b\sin pl$$

$$\therefore\ b = \{ [EIw/P^2 - M_2/P] - [EIw/P^2 - M_1/P]\cos pl \}/\sin pl \quad . \quad (b)$$

the angle, of course, being in radians.

Now $M = 0$ at $x = x_1$

$$\therefore\ 0 = EIw/P - P(a\cos px_1 + b\sin px_1)$$

$$\therefore\ (EIw/P^2)^2(1 + \tan^2 px_1) = a^2 + 2ab\tan px_1 + b^2\tan^2 px_1$$

$$\therefore\ \{ b^2 - (EIw/P^2)^2 \}\tan^2 px_1 + 2ab\tan px_1 + \{ a^2 - (EIw/P^2)^2 \} = 0$$

$$\therefore\ \tan px_1 = \{ -ab \pm (EIw/P^2)\sqrt{[a^2 + b^2 - (EIw/P^2)^2]} \}/\{ b^2 - (EIw/P^2)^2 \}$$

$$\therefore\ px_1 = \tan^{-1}\{ -ab \pm (EIw/P^2)\sqrt{[a^2 + b^2 - (EIw/P^2)^2]} \}/$$

$$[b^2 - (EIw/P^2)^2] \quad . \quad . \quad . \quad . \quad . \quad . \quad (x_1)$$

the angle, of course, being in radians.

This ordinarily gives two real values of x_1 in the bay, at either or both of which either flange or both flanges may be spliced. In the case of spars which are not built up, the complete spar may be spliced at these points, but if the web is a separate member or a number of separate members, it or they should not be spliced here, but $x = x_2$, where the shear stress is zero.

The shear stress is zero where M is a maximum.

$$\therefore\ dM/dx = 0 \text{ when } x = x_2$$

$$\therefore\ -P(-ap\sin px_2 + bp\cos px_2) = 0$$

$$\therefore\ \tan px_2 = b/a$$

$$\therefore\ x_2 = (1/p)\tan^{-1}(b/a) \qquad . \quad . \quad . \quad . \quad (x_2)$$

the angle, of course, being in radians.

This ordinarily gives one real value of x_2 in the bay, which is the point for splicing webs, if these are independent of the flanges.

To find the value of M_{max}, the maximum bending moment in the bay, first find the numerical value of x_2 from equation (x_2) and verify that this falls in the bay, and then substitute this numerical value for x in equation (M) . . . (M_{max}).

It is most important to follow this procedure when finding M_{max}, since any attempt to get a general mathematical expression for it will lead to the introduction of an ambiguous sign which gives infinite trouble. If the procedure here laid down is followed, no such difficulties occur.

2. The Bending Moments in a Bay of a Spar Carrying a Tension and a Distributed Load when the End Bending Moments are known.

Using the same notation as in §1, except that there is now a tension T in the centre line of the spar before deflection instead of a compression, we have:—

$$EId^2y/dx^2 = M = M_1 - Sx + \tfrac{1}{2}wx^2 + Ty$$

$$\therefore\ EId^2y/dx^2 - Ty = M_1 - Sx + \tfrac{1}{2}wx^2$$

The solution of this is:—

$$y = ce^{qx} + de^{-qx} - M_1/T - EIw/T^2 + Sx/T - wx^2/2T$$

$$\text{where } q = \sqrt{(T/EI)} \qquad . \quad . \quad . \quad . \quad . \quad (q)$$

and c and d are constants of integration.

$$\therefore\ M = -EIw/T + T(ce^{qx} + de^{-qx}) \qquad . \quad . \quad . \quad (M)$$

Now $M = M_1$ at $x = 0$ and $M = M_2$ at $x = l$

$$\therefore EIw/T^2 + M_1/T = c + d$$

$$\text{and } EIw/T^2 + M_2/T = ce^{ql} + de^{-ql}$$

$$\therefore c = \{ (EIw/T^2 + M_1/T) - (EIw/T^2 + M_2/T)\, e^{ql} \} / (1 - e^{2ql}) \quad . \quad (c)$$

$$\text{and } d = e^{ql} \{ (EIw/T^2 + M_2/T) - (EIw/T^2 + M_1/T)\, e^{ql} \} / (1 - e^{2ql}) \quad . \quad (d)$$

Now $M = 0$ at $x = x_1$

$$\therefore 0 = -EIw/T + T(ce^{qx_1} + de^{-qx_1})$$

$$\therefore e^{2qx_1} - (EIw/cT^2)\, e^{qx_1} + d/c = 0$$

$$\therefore e^{qx_1} = [EIw/T^2 \pm \sqrt{\{ (EIw/T^2)^2 - 4cd \}}]/2c$$

$$\therefore x_1 = (1/q) \log_e \{ [EIw/T^2 \pm \sqrt{\{ (EIw/T^2)^2 - 4cd \}}]/2c \} \quad . \quad (x_1)$$

This ordinarily gives two real flange splicing points in the bay.

Now $x = x_2$ when M is a maximum and the shear stress is zero.

$$\therefore dM/dx = 0 \text{ when } x = x_2$$

$$\therefore 0 = T(cqe^{qx_2} - dqe^{-qx_2})$$

$$\therefore e^{2qx_1} = d/c$$

$$\therefore x_2 = (1/2q) \log_e (d/c) \quad . \quad . \quad . \quad . \quad . \quad (x_2)$$

This ordinarily gives one real web splicing point in the bay.

To find M_{max}, first find the numerical value of x_2 from the equation (x_2) and verify that this falls in the bay, and then substitute this numerical value for x in equation (M) . . . . . (M_{max})

As before, if this procedure is departed from trouble will ensue.

The formulæ of this § can be deduced from those of §1 by substituting $-T$ for P and simplifying, but the proofs here given are considerably easier.

3. The Bending Moments in a Bay of a Spar Carrying only a Distributed Load when the End Bending Moments are known.

Using the same notation as in §1, except that P does not now occur, we have, by taking moments about the right hand end of the bay:—

$$S = wl/2 + (M_1 - M_2)/l \quad . \quad . \quad . \quad . \quad (S)$$

Also

$$M = M_1 - Sx + wx^2/2 \quad . \quad . \quad . \quad . \quad (M)$$

Now $M = 0$ when $x = x_1$

$$\therefore 0 = M_1 - Sx_1 + wx_1^2/2$$

$$\therefore x_1 = \{ S \pm \sqrt{(S^2 - 2M_1 w)} \}/w \quad . \quad . \quad , \quad (x_1)$$

This ordinarily gives two real flange splicing points in the bay.

Now $x = x_2$ when M is a maximum and the shear stress is zero.

$$\therefore dM/dx = 0 \text{ when } x = x_2$$

$$\therefore 0 = -S + wx_2$$

$$\therefore x_2 = S/w \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (x_2)$$

This ordinarily gives one real web splicing point in the bay.

In this case no ambiguity is introduced by a mathematical evaluation of M_{max}, which can be done by substituting x_2 from equation (x_2) in equation (M), giving:—

$$M_{max} = M_1 - Sx_2 + wx_2^2/2$$

$$\therefore M_{max} = M_1 - S^2/2w \quad . \quad . \quad . \quad . \quad (M_{max})$$

4. Determination of M_1 and M_2 to give Equalised Stresses for the Compression Case.

First of all put $M_2 = M_1$.

Then equations (p), (M), (a), (x_1) and (x_2) of §1 stand, but equation (b) becomes:—

$$b = (EIw/P^2 - M_1/P)(1 - \cos pl)/\sin pl$$

$$\therefore b = a \tan \tfrac{1}{2}pl \qquad (b)$$

$$\therefore x_2 = (1/p) \tan^{-1} \{ \tan \tfrac{1}{2}pl \}$$

This gives one real value of x_2 in the bay, namely:—

$$x_2 = \tfrac{1}{2}l$$

We can now find the value of M_{max} without ambiguity by substituting this value of x_2 in equation (M), giving:—

$$\begin{aligned} M_{max} &= EIw/P - P \{ a \cos \tfrac{1}{2}pl + b \sin \tfrac{1}{2}pl \} \\ &= EIw/P - P \{ a \cos \tfrac{1}{2}pl + a \tan \tfrac{1}{2}pl \sin \tfrac{1}{2}pl \} \\ &= EIw/P - Pa \sec \tfrac{1}{2}pl \\ &= EIw/P - P(EIw/P^2 - M_1/P)/\cos \tfrac{1}{2}pl \\ &= (EIw/P)(1 - 1/\cos \tfrac{1}{2}pl) + M_1/\cos \tfrac{1}{2}pl \end{aligned}$$

Now put $M_{max} = -M_1$

$$\begin{aligned} \therefore M_1 &= (EIw/P)(1 - \cos \tfrac{1}{2}pl)/(1 + \cos \tfrac{1}{2}pl) \\ &= (EIw/P) \tan^2 pl/4 \end{aligned}$$

Therefore if we put $M_1 = (EIw/P) \tan^2 pl/4$

and $M_2 = (EIw/P) \tan^2 pl/4$

we get $M_1 = M_2 = -M_{max}$

and therefore the stresses at three points in the bay (the ends and the centre) are equal as required.

5. Determination of M_1 and M_2 to give Equalised Stresses for the Tension Case.

First of all put $M_2 = M_1$.

Then equations (q), (M), (x_1) and (x_2) of §2 stand, but equations (c) and (d) become:—

$$c = (EIw/T^2 + M_1/T)/(1 + e^{ql}) \qquad (c)$$

and

$$d = e^{ql}(EIw/T^2 + M_1/T)/(1 + e^{ql})$$

$$\therefore d = ce^{ql} \qquad (d)$$

$$\therefore x_2 = (1/2q) \log_e (e^{ql})$$

This gives one real value of x_2 in the bay, namely:—

$$x_2 = l/2$$

We can now find the value of M_{max} without ambiguity by substituting this value of x_2 in equation (M), giving:—

$$\begin{aligned} M_{max} &= -EIw/T + T(ce^{\frac{1}{2}ql} + de^{-\frac{1}{2}ql}) \\ &= -EIw/T + 2Tce^{\frac{1}{2}ql}(EIw/T^2 + M_1/T)/(1 + e^{ql}) \\ &= -(EIw/T)\{1 - 2e^{\frac{1}{2}ql}/(1 + e^{ql})\} + 2M_1e^{\frac{1}{2}ql}/(1 + e^{ql}) \end{aligned}$$

Now put $M_{max} = -M_1$.

$$\therefore M_1 = \{(1 - e^{\frac{1}{2}ql})/(1 + e^{\frac{1}{2}ql})\}^2 EIw/T$$

Therefore if we put

$$M_1 = \{ (1 - e^{\frac{1}{2}ql})/(1 + e^{\frac{1}{2}ql}) \}^2 EIw/T$$

and

$$M_2 = \{ (1 - e^{\frac{1}{2}ql})/(1 + e^{\frac{1}{2}ql}) \}^2 EIw/T$$

we get $M_1 = M_2 = -M_{max}$ and therefore the stresses at three points in the bay (the ends and the centre) are equal as required.

6. Determination of M_1 and M_2 to give Equalised Stresses for the Case with neither Compression nor Tension.

First of all put $M_2 = M_1$.

Then equation (M_{max}) of §3 stands, but equation (S) becomes:—

$$S = wl/2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (S)$$

$$\therefore M_{max} = M_1 - wl^2/8$$

Now put $M_{max} = -M_1$.

$$\therefore M_1 = wl^2/16$$

Therefore if we put

$$M_1 = wl^2/16 \text{ and } M_2 = wl^2/16$$

we get $M_1 = M_2 = -M_{max}$ and therefore the stresses at three points in the bay (the ends and the centre) are equalised as required.

7. Method of Producing the Required End Bending Moments for the Compression Case.

The spars are not continuous but are interrupted by pin joints at all gap strut fittings except at the root of the overhang. These pin joints are not on the centre line of the spar, but are offset.

Then, in the general case (neglecting for the present the bay next inside the overhang), let Δ_n be the upward offset of the pin joint at the left hand end (*i.e.*, the inner end) of the nth bay, the bays being numbered from the junction with the centre section outwards.

Further, the flying wire at its outer end is offset so that it is attached to the spar of the nth bay at a point δ_n below the intersection of the centre lines of the spar and the gap strut.

Then clearly:—

$$M_{1n} = P_n \Delta_n \quad . \quad . \quad . \quad . \quad . \quad . \quad (M_{1n})$$

Also by a consideration of the horizontal forces at the right hand end of the bay we see that the horizontal component of the flying wire tension is $P_n - P_{n+1}$.

$$\therefore M_{2n} = P_{n+1}\Delta_{n+1} - (P_n - P_{n+1})\delta_n \quad . \quad . \quad . \quad (M_{2n})$$

But if the bay in question is the next inside the overhang, though the above equation for M_{1n} stands, the equation for M_{2n} must be modified because Δ_{n+1} does not now exist (the spar being continuous over the right hand support) and P_{n+1} is now zero.

Let M_o be the bending moment at the root of the overhang, then:—

$$M_{2n} = M_o - P_n\delta_n \quad . \quad . \quad . \quad . \quad (M_{2n})^1$$

This applies to the case of a machine with one more bay in the top plane than the bottom, as well as to even decked machines.

8. Method of Producing the Required End Bending Moments for the Tension Case.

In the general case (neglecting for the present the bay next inside the overhang), let Δ_n be the downward offset of the pin joint at the left hand end (*i.e.*, the inner end) of the *n*th bay. It will be remembered that the upward direction is taken as the direction of action of w.

The flying wire at its inner end is offset so that it is attached to the spar of the *nth* bay at a point δ_n above the intersection of the centre lines of the spar and the gap strut.

Normally, of course, we are dealing with a bay of the bottom spar. Then clearly

$$M_{2n} = T_n \Delta_{n+1} \quad . \quad . \quad . \quad . \quad . \quad (M_{2n})$$

Also, since the horizontal component of the flying wire tension is $T_{n-1} - T_n$,

$$M_{1n} = T_{n-1}\Delta_n + (T_{n-1} - T_n)\delta_n \quad . \quad . \quad . \quad (M_{1n})$$

But for the bay next inside the overhang, in the case of the bottom spar of a machine which has a top plane extension (so that T_n is not zero), though the above equation for M_{1n} stands, Δ_{n+1} does not exist and we get for M_{2n}:—

$$M_{2n} = M_o - T_n\delta_{n+1} \quad . \quad . \quad . \quad . \quad (M_{2n})^1$$

M_o being the bending moment at the root of the overhang.

9. Method of Producing the Required End Bending Moments for the Case with neither Tension nor Compression.

Such a case occurs, for instance, in the bay of the bottom plane next inside the overhang on an even decked machine in normal flight.

Then with the notation of §8, but remembering that $T_n = 0$, we have:—

$$M_{1n} = T_{n-1}(\Delta_n + \delta_n) \quad . \quad . \quad . \quad . \quad (M_{1n})$$

and

$$M_{2n} = M_o \quad . \quad . \quad . \quad . \quad . \quad (M_{2n})$$

10. A Special Limit to the Length of the Overhang.

Lieutenant A. H. Stuart, R.N.V.R., has investigated the vibration of wing tips.

The conclusion he arrives at is that the overhang must not exceed 3/7 of the length of the next bay inwards.

It is by no means clear that the last word has yet been said on this subject, but for our present purpose it is necessary to accept this limitation at face value.

11. The Determination of the Best Lengths for the Bays.

It is supposed that the design of the machine has already reached the stage when the span, chord, gap, wing tip shape, dihedral angle, position of spars in the fore and aft direction, total weight of machine and number of bays required are fixed.

Seeing that the top front spar is the heaviest, it will obviously pay us to concentrate chiefly on this spar in order to save as much weight as possible on the whole wing structure.

Considering, therefore, this spar in what is expected to prove the most severe condition of loading, and including the load factor in our numerical work, we know the value of w, and of course we also know the value of E for the material we have chosen for the spar.

Now consider the first bay out from the centre section. Although we do not yet know its length we can still find the value of P in this bay, by using the Method of Sections.* In doing this, however, we have to take as an approximation the designed gap instead of the effective gap, which differs from it slightly in consequence of the offsetting of pin joints in the spars.

The next step is to design a reasonable looking spar by guess, and find for it the values of A, the cross-sectional area, Z the modulus of section, and I. This spar section will be used for the present in all the bays, but not, probably, in the overhang.

Now let Σ be the elastic limit of the material chosen for the spars.

Then, if the stresses are equalised, we have, of course, since the stress at the end may then reach the elastic limit,

$$M_1/Z + P/A = \Sigma$$

Also, for equalised stresses, we have from §4,

$$M_1 = (EIw/P)\tan^2(pl/4)$$

where

$$p = \sqrt{(P/EI)}$$

$$\therefore\ M_1 = Z\Sigma - PZ/A$$

and

$$pl/4 = \tan^{-1}\sqrt{\{(M_1P)/EIw\}}$$

$$\therefore\ l = 4\sqrt{(EI/P)}\tan^{-1}\sqrt{\{P(Z\Sigma - PZ/A)/EIw\}} \quad . \quad . \quad (l)$$

Now we know A, Z, I, E, w, Σ, and we have already found P for the first bay, therefore from equation (l) we can at once get the length of the first bay.

This done, we find P for the second bay by a process similar to that which gave us P in the first bay. Then, with this new value of P but with the same values of A, Z, I, E, w, Σ, as before, we find l for the second bay from equation (l).

This procedure is followed again to find the value of l for the third bay, and so on for the number of bays already decided on.

Now consider the length of overhang which remains after the bay lengths have been found as above. If this exceeds 3/7 of the length of the next bay in, it is too long, as we see from §10, while if it is less than this figure, or negative, it is too short.

Now go back and repeat the work of this § with a stronger spar if the overhang was too long, but with a weaker spar if the overhang was too short.

A few such trials with different sizes of spar will determine a spar size and an accompanying set of values of l which gives the correct overhang of 3/7 of the next bay in.

It is now necessary to check the result so far obtained by finding the value of M_o by the method given in "Aeroplane Structures," by Pippard and Pritchard, §95. Then the stress at the root of the overhang is M_o/Z; if this is less than Σ, accept the bays we have as final, but note that the overhang spar will be able to be reduced a bit in strength later on; if, on the other hand, M_o/Z is greater than Σ we must revise our work by trying a slightly stronger spar and continuing our trials till we get $M_o/Z = \Sigma$.

It should be noted that the number of trials involved in the work can be kept down to a minimum by plotting the spar size characteristic (flange thickness, for instance) and the lengths of the bays against length of overhang/length of next bay in and finding the spar and bay lengths which give 3/7 for this figure,

* See "Aeroplane Structures," by Pippard and Pritchard.

or by plotting the spar size characteristic and bay lengths against M_0/Z and finding the spar and bay lengths for $M_0/Z = \Sigma$, as the case may be.

It will be found in practice that the 3/7 criterion almost always settles the matter, thus rendering further trial and error unnecessary.

In the case of a multi-bay machine it is a good plan to repeat the work for one bay less and for one bay more than the number originally decided on in the design. This may lead to a revision of the decision as to how many bays to use, and lighten the wing structure.

In the case of a one-bay machine the first part of the work, namely, finding a system to meet the 3/7 criterion, takes a rather simpler form.

We know l for the bay at once, as it is 7/10 of the span, so we have only to try out a series of spars till we find one which gives the correct value for l when substituted in equation (*l*).

The second part of the work, of course, follows standard lines.

Having found the best bay lengths by the procedure here given, the designer will presumably decide on round numbers which are nearly equal to them and use these in his design. Also he will doubtless use the same bay lengths for the top back spar and for the bottom spars as a matter of convenience, although in theory it would be preferable to determine these independently; as, however, that would lead to gap and drift struts pointing in all sorts of odd directions, the designer is not very likely to proceed to such an extreme.

12. Determination of the Spar Section for a Bay of Predetermined Length in the Compression Case.

In the case of the top front spar, of course, we determined the spar section in §11, but in the case of the other spars, although we settled the bay lengths in §11, we have still to find the spar sections.

Take any bay of any of the other three spars.

Then if the condition of loading which is expected to prove the worst for this bay brings the bay into compression, we have, from §4, as a condition for equalised stresses:—

$$M_1 = (EIw/P)\tan^2 pl/4$$

where

$$p = \sqrt{(P/EI)}$$

and, since the stress at the end of the bay is equal to the elastic limit:—

$$M_1 = Z\Sigma - PZ/A$$

$$\therefore \tan^2 \sqrt{(P/EI)}\, l/4 = (PZ/EIw)(\Sigma - P/A)$$

Now P is known to a sufficient degree of approximation by the method of sections, l is already determined, E and Σ are known for the spar material chosen for this bay, and w is known.

Therefore the above equation is a relation between the unknowns I, Z and A.

We therefore proceed to choose a likely looking spar section and find I, Z and A for it. Then substitute these values in the above equation, and, if the equation is not satisfied, try another spar, and so on until a spar is found which satisfies the equation exactly. This is then the required spar section.

The trial and error work can be shortened by plotting the left hand side and the right hand side of the equation on a base of spar size characteristic. The intersection of the two curves gives the spar size characteristic required.

13. Determination of the Spar Section for a Bay of Predetermined Length in the Tension Case.

For the tension case we have from §5, as a condition of equalised stresses:—

$$M_1 = \{ (1 - e^{lql}) / (1 + e^{lql}) \}^2 EIw/T$$

where

$$q = \sqrt{(T/EI)}$$

while the condition for the elastic limit is:—

$$M_1 = Z\Sigma - TZ/A$$

$$\therefore \left[\frac{1 - e^{\sqrt{(T/EI)}\, l/2}}{1 + e^{\sqrt{(T/EI)}\, l/2}} \right]^2 = (TZ/EIw)(\Sigma - T/A)$$

The spar section required is found from this equation by trial and error as in §12.

14. Determination of the Spar Section for a Bay of Predetermined Length in the Case with neither Compression nor Tension.

For this case we have from §6, as a condition for equalised stresses:—

$$M_1 = wl^2/16$$

while the condition for the elastic limit is:—

$$M_1 = Z\Sigma$$

$$\therefore Z = wl^2/16\Sigma$$

In this case trial and error does not come in, but a spar is designed at once to give the above value for Z, and that is the spar section required.

15. Determination of the Δ's and δ's for the Compression Case.

The length of the bay in question having been fixed, and a spar section found to give equalised stresses, by the methods of §§11 and 12, we have, from §7, in the general case:—

$$M_{1n} = P_n \Delta_n$$

and

$$M_{2n} = P_{n+1}\Delta_{n+1} - (P_n - P_{n+1})\,\delta_n$$

also, since the stresses are equalised:—

$$M_{1n} = Z_n\Sigma - P_n Z_n/A_n$$

and

$$M_{2n} = Z_n\Sigma - P_n Z_n/A_n$$

$$\therefore \Delta_n = Z_n\Sigma/P_n - Z_n/A_n \quad . \quad . \quad . \quad . \quad . \quad (\Delta_n)$$

$$\therefore \Delta_{n+1} = Z_{n+1}\Sigma/P_{n+1} - Z_{n+1}/A_{n+1}$$

$$\therefore Z_n\Sigma - P_n Z_n/A_n = M_{2n} = Z_{n+1}\Sigma - P_{n+1}Z_{n+1}/A_{n+1} - (P_n - P_{n+1})\,\delta_n$$

$$\therefore \delta_n = \{ Z_{n+1}\Sigma - Z_n\Sigma + P_n Z_n/A_n - P_{n+1}Z_{n+1}/A_{n+1} \} / (P_n - P_{n+1}) \qquad (\delta_n)$$

But if the bay in question is the next inside the overhang, we have, from §7:—

$$M_{1n} = P_n \Delta_n$$

and

$$M_{2n} = M_o - P_n \delta_n$$

while we still have the equations:—

$$M_{1n} = Z_n\Sigma - P_n Z_n/A_n$$

and

$$M_{2n} = Z_n\Sigma - P_n Z_n/A_n$$

therefore the above equation for Δ_n stands, but we get in the present case:—

$$\delta_n = M_o/P_n - Z_n\Sigma/P_n + Z_n/A_n \quad . \quad . \quad . \quad (\delta_n)^1$$

It will be found in practice that the values of δ are quite reasonable, and round number values approximating to them will doubtless be adopted by the designer as final, but it will probably be found necessary to change the value of Δ in some of the bays rather drastically in order to avoid complexity of fitting design due to hinge points falling considerably outside the spar section.

16. Determination of the Δ's and δ's for the Tension Case.

The length of the bay having been found by the method of §11 and the spar section by §13, we have, from §8, in the general case:—

$$M_{1n} = T_{n-1}\Delta_n + (T_{n-1} - T_n)\,\delta_n$$

and

$$M_{2n} = T_n\Delta_{n+1}$$

also, since the stresses are equalised:—

$$M_{1n} = Z_n\Sigma - T_nZ_n/A_n$$

and

$$M_{2n} = Z_n\Sigma - T_nZ_n/A_n$$

$$\therefore \Delta_{n+1} = M_{2n}/T_n = Z_n\Sigma/T_n - Z_n/A_n$$

$$\therefore \Delta_n = Z_{n-1}\Sigma/T_{n-1} - Z_{n-1}/A_{n-1} \quad . \quad . \quad . \quad (\Delta_n)$$

$$\therefore Z_n\Sigma - T_nZ_n/A_n = M_{1n} = Z_{n-1}\Sigma - T_{n-1}Z_{n-1}/A_{n-1} + (T_{n-1} - T_n)\,\delta_n$$

$$\therefore \delta_n = \{ Z_n\Sigma - Z_{n-1}\Sigma - T_nZ_n/A_n + T_{n-1}Z_{n-1}/A_{n-1} \}/(T_{n-1} - T_n) \quad (\delta_n)$$

But if the bay in question is the next inside the overhang, we have, from §8, in the case of the bottom spar of a machine which has a top plane extension:—

$$M_{1n} = T_{n-1}\Delta_n + (T_{n-1} - T_n)\,\delta_n \quad . \quad . \quad . \quad (1)$$

and

$$M_{2n} = M_o - T_n\delta_{n+1} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

while, of course:—

$$M_{2(n-1)} = T_{n-1}\Delta_n \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and, as before:—

$$M_{1n} = Z_n\Sigma - T_nZ_n/A_n \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and

$$M_{2n} = Z_n\Sigma - T_nZ_n/A_n \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and, of course:—

$$M_{2(n-1)} = Z_{n-1}\Sigma - T_{n-1}Z_{n-1}/A_{n-1} \quad . \quad . \quad . \quad (6)$$

From equations (3) and (6) we see that the above equation for Δ_n stands, and then from this fact and from equations (1) and (4) we see that the above equation for δ_n also stands. We have, however, from equations (2) and (5):—

$$Z_n\Sigma - T_nZ_n/A_n = M_{2n} = M_o - T_n\delta_{n+1}$$

$$\therefore \delta_{n+1} = M_o/T_n - Z_n\Sigma/T_n + Z_n/A_n \quad . \quad . \quad . \quad (\delta_{n+1})^1$$

17. Determination of the Δ's and δ's for the Case with neither Tension nor Compression.

The length of the bay having been found by the method of §11 and the spar section by §14, we have, from §9:—

$$M_{1n} = T_{n-1}(\Delta_n + \delta_n)$$

also, since bay $(n-1)$ is in tension, we have from §8:—

$$M_{2(n-1)} = T_{n-1}\Delta_n$$

$$\therefore \Delta_n = M_{2(n-1)}/T_{n-1}$$

and

$$\delta_n = (M_{1n} - M_{2(n-1)})/T_{n-1}$$

also we have, for equalised stresses:—

$$M_{1n} = Z_n\Sigma$$

and

$$M_{2(n-1)} = Z_{n-1}\Sigma - T_{n-1}Z_{n-1}/A_{n-1}$$

$$\therefore \Delta_n = Z_{n-1}\Sigma/T_{n-1} - Z_{n-1}/A_{n-1} \quad . \quad . \quad . \quad (\Delta_n)$$

and

$$\delta_n = \{ Z_n\Sigma - Z_{n-1}\Sigma + T_{n-1}Z_{n-1}/A_{n-1} \}/T_{n-1} \quad . \quad . \quad (\delta_n)$$

18. The Practical Design of Spars with Offset Pin Joints.

When applying the methods of design here given in a practical case it is not, of course, necessary to work through all the foregoing mathematics. All that we need do is to use the following procedure, which will be found to be quite quick:—

(1) Work right through §11 for the worst case of loading on the top front spar thus finding the ideal bay lengths for this spar. Then fix final bay lengths for all the spars by taking convenient figures approximately equal to these ideal values and applying them to all the spars, and note them. Note also the centre section bay lengths.

(2) Note the top front spar section found in working through §11 and find the spar sections in all the bays of all the other spars (including the centre section) by solving the final equations of §§12, 13 and 14, as explained at the ends of these §§, and note them.

(3) Find all the Δ's and δ's all over the machine by the formulæ marked (Δ_n), (δ_n), $(\delta_n)'$ and $(\delta_{n+1})'$ in §§15, 16 and 17. Arbitrarily alter such of these as are impracticable and then note them.

(4) Make a new list of spar sections all over the machine by taking convenient sizes not weaker than those of (2), adding, however, a bit of extra strength in any bay that has been arbitrarily lengthened under (1) or has had its Δ or δ *either increased or decreased* under (3).

(5) With the bay lengths of (1), the offsets of (3) and the spar sections of (4), check over the stresses in each bay of the machine under *all* loading conditions (it may be found, for instance, that the offsets which have strengthened the top front spar in normal flight with *c.p.* forward have weakened it unduly for the case of nose-diving). If any bay is weak, try a slightly stronger spar for that bay and re-check that bay only for *all* loading conditions. In checking a bay, first find P or T for the bay by the method of sections, but taking account of the offsets which are now known (*i.e.*, do not neglect the offsets in comparison with the gap). Then find M_1 and M_2 from the formulæ marked (M_{1n}), (M_{2n}) and $(M_{2n})'$ of §§7, 8 and 9, whichever is applicable, finding M_o, if it happens to come in.* Then find M_{max} as described at the end of §1, 2 or 3, as the case may be. Now, since M_1, M_2 and M_{max} are known, the stresses at the ends of the bay and at the point of maximum bending moment can be written down. These must, of course, be less than Σ to pass the bay.

(6) If the spar *must* be spliced, in spite of the short lengths it is already cut up into by the pin joints, find x_1 and x_2 by the formulæ so marked in §§1, 2 and 3 for *each* condition of loading. Then choose definite values for x_1 and x_2 to give the most reasonable looking compromise between the various values for different conditions of loading (in doing so, it will of course be necessary to adhere more closely to the values corresponding to severely stressed conditions). Next

* See "Aeroplane Structures," by Pippard and Pritchard. § 95.

draw Bending Moment and Shear Force diagrams for all the conditions of loading and note the worst stresses falling on the splices at the places that have been chosen. If these stresses do not exceed half the permissible stresses in unspliced material, the splices may be made at these points. If, however, points cannot be found to satisfy these conditions, then splicing is not permissible.

This analysis of splicing points will be found to be laborious, and on the whole it will be advisable to avoid splicing spars designed on this principle of Offset Spar Joints.